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Volume 37, Number 9 September 2007

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ON THE COVER

Selenite crystals reach massive proportions in the Cavern of Crystals at Naica, Mexico. (Javier Trueba photo/Madrid Scientific Films)

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NAICA'S SELENITE MEGACRYSTALS

Scientists Reveal New Findings on the Cavė of Crystals

Story by Bob Jones

In 2000, miners digging a tunnel 1,000 feet underground in a silver, lead mine at Naica, Chihuahua, Mexico, broke into a huge cavern with selenite crystals up to 50 feet long! After a visit to this steamy underground fairyland early in 2001, I was able to report on this amazing cave full of monster crystals in the September 2001 issue of *Rock & Gem.*

The cavern proved to be a unique marvel of crystal growth. Selenite crystals as tall as telephone poles and as thick as tree trunks had grown in this amazing limestone cavern. Large crystals are not unusual, but such gigantic growth is almost unheard of in mining annals.

JAVIER TRUEBA/MADRID SCIENTIFIC FILMS

Many of the telephone pole-size crystals terminate into the ceiling of the cavern.

JAVIER TRUEBA/MADRID SCIENTIFIC FILMS

The selenite megacrystals in the Cueva de los Cristales measure more than 12 meters long.

Going into the cavern was a bit risky. Anyone who entered the cavern immediately felt the smothering effect of temperatures exceeding 140 degrees and humidity nudging 100 percent. One could not venture far from the entrance into this forest of crystals, since heat exhaustion and disorientation could result in serious injury, even death. The mining company, well aware of the danger, would only allow visitors in the cavern while accompanied by experienced miner/guides.

As word spread about the wonder, the mining company, Compania Peñoles Unidad Naica, simply could not continue to assign guides—who should be mining ore—and equipment to truck the increasing numbers of visitors 1,000 feet underground to see this underground mineralogical site. It sealed the cavern off and made arrangements to allow scientists into the cavern to study the unique crystals.

One scientist who was given the study opportunity was Juan Manuel Garcia-Ruiz of the Universidad Granada, Spain, who supplied the information included in this article. Accompanying Garcia-Ruiz in the research were company scientist Roberto Villasuso; Angels Canals, Universitat Barcelona; Carlos Ayora, Institut de Ciencies de la Terra, Barcelona; and Fermin Otalora, Instituto Andaluz de Ciencias de la Terra, Barcelona. The technical information in this article is taken from an article published by these scientists titled "Formation of natural gypsum megacrystals in Naica, Mexico" (*Geology* magazine, April 2007, pp. 327-330). I was first alerted to the work by a news item from the BBC news Web site (http://news.bbc.co.uk/). *Rock & Gem* is indebted to Sr. Garcia-Ruiz for his help in supplying the information used here. He also helped us contact Javier Trueba, whose photographs accompanied the *Geology* article and the BBC item.

JAVIER TRUEBA/MADRID SCIENTIFIC FILMS

The walls and floor of the Cueva de los Cristales are covered with selenite gypsum crystals.

Properly attired against the heat and humidity, the scientists entered the cavern in order to collect fluid inclusions from the crystals. Fluid inclusions represent the original solutions from which the crystals grew. They have long been one of the key sources of information on conditions that existed when any crystals resulting from hydrothermal solutions formed. These giants had developed from a hot, watery (hydrothermal) solution. As the crystals grew, some of them trapped the original solution. The environment in which these crystals developed had to be unusual, so the university studies focused on conditions within the cavern at the time of development.

The rich silver, lead, zinc ore deposits at Naica had developed from hydrothermal solutions emanating from deep in the earth. It has been proved that the solution was high in salinity. It had originated deep underground, where a magmatic mass had intruded the crust. The mineral-rich solutions from this magma mass rose slowly through two major faults and some smaller ones in the Sierra de Naica Mountains and penetrated the host limestone formations in the area. This gradual ascent of the hydrothermal solutions resulted in a gradual decrease in the solution's temperature.

As solutions cool, minerals in the solution begin to crystallize. The minerals that crystallized first included the major ore minerals of the deposit, like sphalerite, pyrite, galena and chalcopyrite. As these high-temperature crystals form, the minerals that crystallize at lower temperatures remain in solution, which becomes more concentrated as it continues to move upward.

During the hydrothermal process, the sulfides slowly break down and release the sulfate radical into the solution. This combines with some of the water in the solution to form sulfuric acid. As this acidic hydrothermal solution encounters limestone, the limestone releases calcium, which joins with the sulfate radical to form a fairly high-temperature calcium sulfate mineral, anhydrite.

The Naica deposit happens to be rich in anhydrite. Massive anhydrite is often encountered during mining at Naica, and fine crystal specimens have sometimes been collected by miners. Some of the finest anhydrite crystals ever found in Mexico have come from the Naica mine.

continued on next page

One particular source was a water course that produced quantities of lovely gray-blue blades to 7 inches long. Many of these anhydrites were in intergrown clusters, making very showy display specimens. Interestingly, these anhydrite crystals were seldom found perfectly glassy and smooth. Their terminations are usually uneven and their prism faces often slightly grooved, suggesting some later solution caused some alteration and loss of material after these crystals developed.

One unusual crystal variety of anhydrite found at Naica is diverging groups of anhydrite completely enclosed in white, crystalline selenite gypsum. This is evidence of a change in conditions as the anhydrite formed. The change resulted in the growth of selenite, which enveloped the original anhydrite crystals.

The presence of anhydrite's chemical components in the solutions that would ultimately develop the Cueva de los Cristales was important, and typical of the Naica deposit. The Garcia-Ruiz research, as well as other research, has shown that anhydrite crystallizes from solution when the temperature of the solution is above 56 to 58 degrees Celsius. This temperature is the point of nucleation for this particular mineral. Evidence shows anhydrite did form in the Cueva de los Cristales preceding the development of the selenite.

If the temperature of the solution were to drop slightly below 56 degrees Celsius, anhydrite could not form. If it had already formed, it would slowly dissolve back into solution. With the solution still rich in calcium and the sulfate radical present, the stage is set for the growth of selenite crystals.

Selenite, a calcium sulfate hydrate, forms just below the anhydrite range of temperatures. Its temperature of nucleation is around 54 degrees Celsius. Many caverns and vugs in the mines of Mexico hold plenty of selenite crystals, formed from solutions that have obviously been below the nucleation temperature of anhydrite. In fact, selenite gypsum is probably the most common non-ore mineral found in Mexican sulfide mines.

Evidence of selenite formation is everywhere underground at Naica. We certainly saw plenty of it. During our visit to see the huge crystals, as we walked the tunnel leading to the Cueva de los Cristales, we observed plenty of small vugs of selenite crystals and even explored a smaller version of the Cueva de los Cristales, a small cavern with equally amazing crystals.

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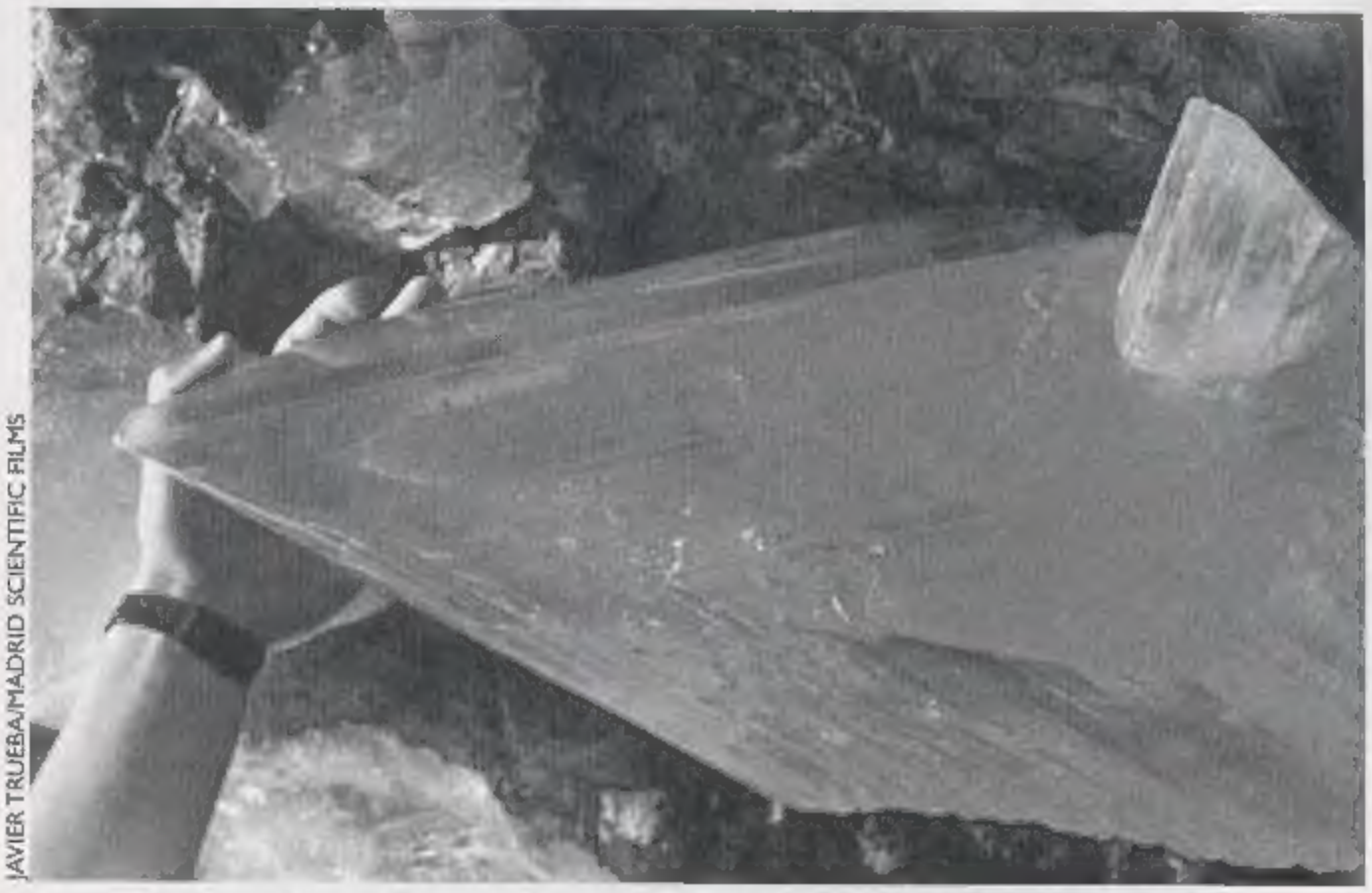

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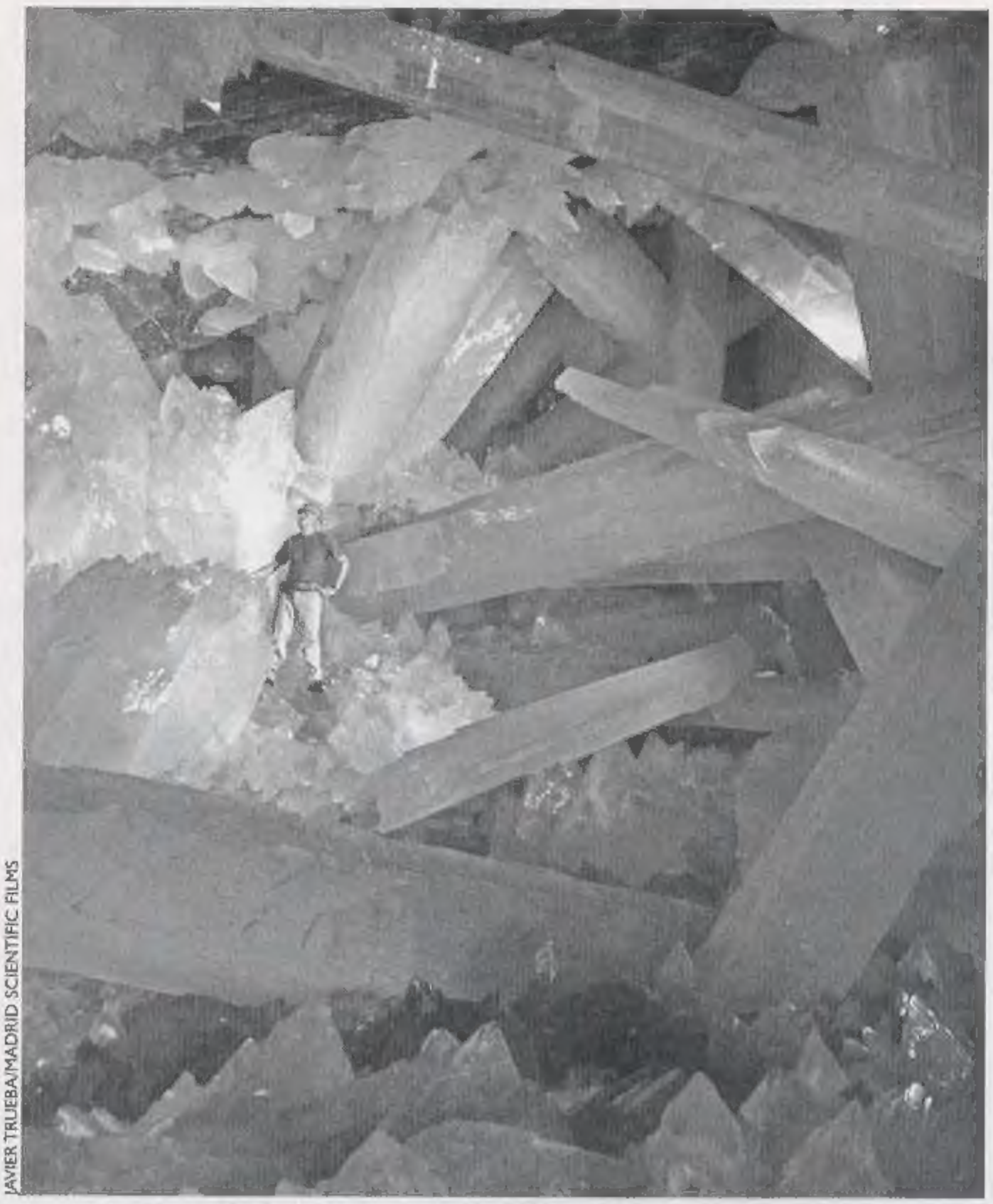
The large size of the crystals clouds their normal transparency.



JAVIER TRUEBA/MADRID SCIENTIFIC FILMS

A slight change in temperature makes the difference between numerous small crystals and giant crystals.

This briefly explains why selenite crystals formed in the cavern, as opposed to anhydrite crystals. The temperature of the solution in the cavern was not hot enough to maintain anhydrite, once formed, but perfectly suited to encourage the growth of selenite. The scientists have a superb explanation of this anhydrite/selenite relationship.

After the anhydrite formed, the solution cooled slightly, dissolving the anhydrite back into solution in the form of calcium and the sulfate radical. With these ingredients present, along with the water in the solution, calcium sulfate hydrate, or selenite gypsum, could form.

This explains why selenite formed in the Cueva de los Cristales, but it does nothing to explain why this particular cavern held such giant crystals. Selenite crystal cavities and even small caves are fairly common in many Mexican mines. I have been in several selenite caves in Mexico. The Buena Tierra Mine held a cavern whose floor was covered with selenite crystals ranging from under 2 inches to 7 or 8 feet long.

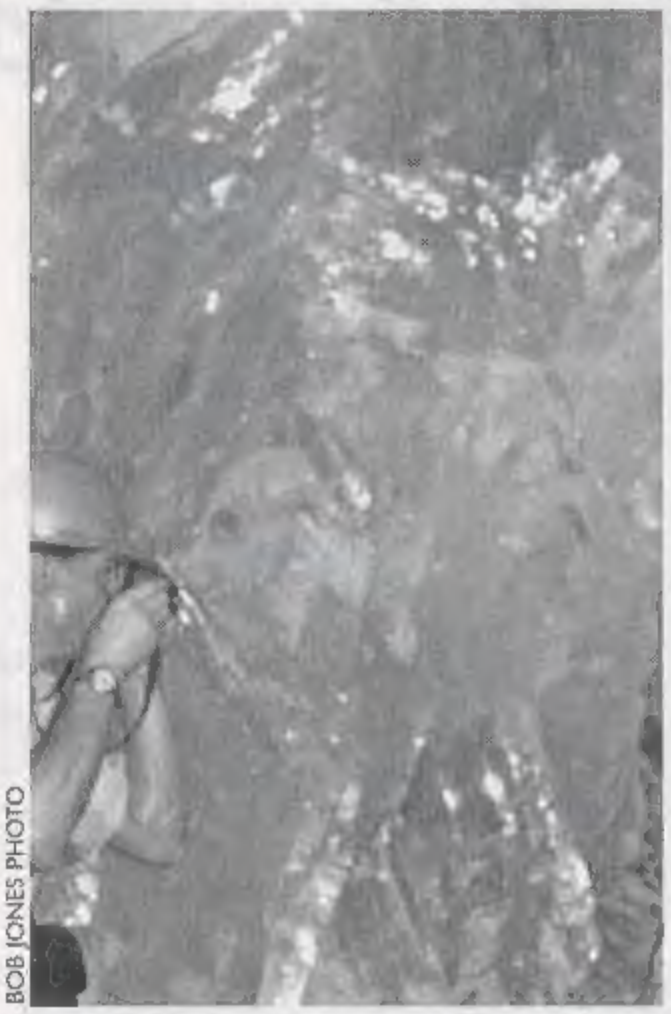
The Cave of Swords at Naica, another cave we visited, has tens of thousands of crystals from inches long to a few feet long. So why didn't these caverns develop multiyard-long crystals like the Cueva de los Cristales? Garcia-Ruiz and his associates believe they have found the answer. Two conditions had to be present.

The first condition was that the temperature of the solution had reached the point at which anhydrite could no longer nucleate and selenite could. Nucleation is the point at which a mineral begins to leave solution and form crystals. This is controlled by temperature, pressure, and other factors. In this case, temperature was the main controlling factor.

The scientists suggest that anhydrite formed, but was soon dissolved back into solution, thus supplying the material for the later selenite to develop. They call the solution a "self-feeding mechanism." This means that no new material was needed, since all the ingredients for selenite to form were already there in solution.

The second condition, according to the Garcia-Ruiz report, is that the temperature of selenite crystallization is maintained and remains constant for long, long periods of time. This enables the initial selenite crystals to continue to grow, and grow, and grow!

If the temperature were to drop considerably, then any large crystal growth would cease and a large number of smaller crystals would begin to grow. The Cave of Swords is a good example of this, as was the cave we saw at the Buena Tierra Mine years earlier.



BOB JONES PHOTO

Evan Jones examines a cave wall completely covered with thick, crystallized selenite gypsum.

If ideal conditions are maintained, however, the solution can devote its contents to the growth of large, individual crystals such as those in the Cueva de los Cristales. One has to wonder how long it took for such monster crystals to grow. Scientists point out that the rate of nucleation has to be very slow in order for large crystals to grow. A rapid rate of nucleation results in myriad smaller crystals.

With this excellent research, we now have good evidence to explain why the Cueva de los Cristales crystals are megacrystals. The time it took for them to develop can be inferred from the fluid inclusions and the growth of these crystals. The Garcia-Ruiz research suggests that the critical temperature in the solution had to have been maintained over many thousands of years, while the self-feeding mechanism worked and the giants grew. Even when crystal growth stopped briefly, as it apparently had, nothing in the environment changed significantly; therefore, when crystal growth resumed, it built on the already established crystals.

> "What I find quite interesting in the report is that these scientists suggest there is a distinct possibility that other such caverns might be encountered at Naica in the future."

What I find quite interesting in the report is that these scientists suggest there is a distinct possibility that other such caverns might be encountered at Naica in the future. Wouldn't that be neat?

During our 2001 visit, we were taken into a smaller cave by climbing a ladder and crawling through a small opening. It held crystals as large as those in the Cueva de los Cristales. In fact, we speculated that this cavern might be the opposite end of the main cavern. That remains to be proved.

The Garcia-Ruiz group also makes other important observations. The cavern, they say, is accessible only because water has been pumped from the mine's depths to make ore mining possible. They also point out that the huge crystals can be preserved only if the cavern is kept humid and hot.

Some of the crystals are lying horizontally. The Mexicans call them *vigas* (beams). The water in the cavern offers these monsters considerable buoyant support. Selenite is a heavy mineral, and this support must be maintained. If the support were lost, these very heavy crystals would collapse. Keep in mind that selenite has perfect cleavage, so it is easily stressed and broken. Some of these beams actually have huge aggregates of crystals on them, adding to their weight. The treelike crystals have grown nearly vertically from the cavern floor, sometimes reaching the ceiling of the cavern.

This explanation is just a brief summary of the findings reported in the *Geology* article. Interested readers are urged to obtain a copy of this magazine. Published by the Geological Society of America, it contains excellent diagrams of the Naica deposit and graphs of crystal development. You'll find the more complete, detailed and accurate explanation of the processes that led to this amazing crystal cavern most interesting and informative. Write to Geological Society of America, P.O. Box 9140, Boulder, CO 80301-9140, call (303) 357-1000, or visit www.geosociety.org/pubs/.

Editor's Note: For a discussion of Editor Bob Jones's 2001 visit to the Naica mine and its Cueva de los Cristales, refer to his On the Rocks column on page 98 of this issue.

Shop Talk

by William A. Kappele

Uses for Leaverite

Those of you who have followed this column for any length of time have probably noticed me talking about leaverite, that common rock that seems to turn up in all of our storage spots sooner or later. I may have a bit more than the average rockhound, since I seem to have a stronger than average compulsion to bring this stuff home instead of doing what the name implies and "leave 'er right where you find her." Consequently, I have a several lifetimes supply of this pretty, but generally considered useless, material. I feel bad about that, so I spend too much time dreaming up nonstandard uses for these "gems."

Recently, I was watching a cable program on the Do It Yourself Network in which a lady was embedding small photos of her dog in resin using a mold in the shape of a plate. This triggered the leaverite center in my brain, and I remembered that craft stores sell molds for resins in a wide variety of shapes and sizes, including cabochon shapes. It would be very simple to cut some favorite scraps into thin slabs, then break the slabs (if they don't fall apart by themselves) into tiny chips and cast them in resin in a cabochon mold.

There are lots of sites on the Internet that show the process of mixing and pouring the resin, and the material usually comes with instructions. Basically, the process involves mixing resin and hardener in the proper proportions; pouring a first layer; waiting 20 minutes or so; pouring a second layer, into which you embed the rock chips; and finally pouring a third layer to seal everything in. The final layer could be colored to emphasize the rock chips. It's all about letting your imagination run wild.

Of course, cabochon shapes are not the only ones to use for embedding. I'm sure you have all seen those dome-shaped resin pieces containing a lovely scorpion or tarantula. They seem to be in every gift shop in the West. If these beasts aren't your cup of tea, how about embedding a pyrite cube, a turquoise nugget, a small geode half, or any number of neat rocks you have stored away in boxes?

Another idea is to use a scrap of window glass instead of a mold. Build a dam of putty or a similar substance to contain the resin and, using the same three-step technique, pour some small, flat tiles. These could be made into mirror frames, door panels, lamp shades, etc. using standard stained-glass techniques. These tiles could even be glued to the inside of an existing window where you would like a little more privacy. They could also be used in panels in a folding privacy screen.

Crank up the old thinking box and I'm sure you will come up with even better ideas. When you do, send me some pictures.

Please feel free to contact me if you have a suggestion or comment about this or any of my Shop Talk columns. My e-mail is quappelle@cox.net, or write to me at 25231 Pericia Dr., Mission Viejo, CA 92691.

Septarian Nodules

Mysterious Mudballs with a Surprise in the Center

Story and Photos by Bill Evans

Some of the oddest sources of fine mineral specimens and fossils are septarian nodules, a type of concretion found in certain sedimentary rocks. Septarian nodules are special because, instead of solid mud or a bit of organic matter at their core, they often contain minerals, sometimes in discrete crystals.

Concretions are solid nodules that form as mud balls on the bottom of a sea or lake. The weight of the accumulation compacts the earlier deposits, and eventually shale rock is the product. The remains of organisms that have died accumulate with the mud. This is important to the formation of mud nodules; the bacterial action on animal and plant remains releases material that helps solidify and harden the mud surrounding the organic matter. Concretions almost always lack crystals in their interior, although there are a few unusual and important exceptions. Solid concretions can, however, form around fossil remains.

Eventually, the sea or lake recedes, and the mud layers slowly dry up, as do the nodules. As they dry up, the nodules tend to crack. Over a long period of time, the mud is compressed into shale and the mud balls, now concretions, are locked in place. Unless later solutions come and invade those shrunken and cracked concretions, no crystals can develop internally.

If mineral-rich solutions are introduced, the chances of a septarian nodule forming are enhanced. If the solutions fill the cracks, the precipitation of mineral matter can commence and fine crystallized minerals may result.

While all septarian nodules are concretions, having formed in much the same way, not all concretions are septarian nodules. The origin of the name is somewhat debated. In their wonderful book *Geodes: Nature's Treasures* (Gem Guides Book Co., 2006), June Culp Zeitner and Brad Cross offer this explanation: "A thin wall of calcite was transformed into aragonite ... dividing the outer gray clay exteriors from the calcite centers. Because of this dividing wall

The phosphate septarian nodules from Fairfield, Utah, are the most colorful and complex nodules ever found.

Some of the more popular decorative objects carved from Orderville, Utah, septarian nodules are bears with calcite-lined stomachs.

(*septum* in Latin), the nodules are called [s]eptarians" (p. 244). According to the online encyclopedia Wikipedia, septarian nodules are named after their "angular cavities or cracks, which are called 'septaria'" (http://en.wikipedia.org/wiki/Concretion).

There are several important sources of septarian nodules in the United States.

FAIRFIELD, UTAH

The magnificent nodules that occur at Fairfield, Utah, are more or less solid and filled with the green phosphate mineral variscite, which makes them eagerly sought by the lapidary and mineral collector. In fact, they are among the more valuable concretions ever mined. In addition to their colorful variscite content, they sometimes have small vugs that often hold microcrystals of rare phosphate species.

This raises the question, are these simply concretions of phosphate minerals, or are they septarian nodules offering both solid, colorful variscite, crandellite, and like minerals, along with a dozen or so uncommon to rare phosphate species? I choose to give them the latter designation, though some texts simply describe these nodules as concretions, without considering their importance as mineral specimens. In fact, several of the species found at Fairfield were new to the mineral world, so the nodules ended up being type locality specimens. The Fairfield concretions are among the most valuable concretions/septarian nodules ever found.

The Fairfield variscites were known before 1894, and the deposit came to be called the Utahlite Mine. Tons of the green beauties were mined as the 19th century was coming to a close. Some of the masses, measuring over a foot across, could be used in carvings and spheres, while the more colorful ones could be slabbed and polished. Each slab from a particular piece would be a colorful treat for the lapidary. Bowls, spheres, slices and an assortment of colorful jewelry stones could be created from these colorful phosphate concretions.

The Utahlite deposit was diligently worked and produced tons of nodules over a period of 15 years or more. Slowly, the deposit played out and serious mining ceased. Small efforts continued during the first third of the 20th century, but no large quantities were forthcoming during that time.

By 1936, the variscite property was no longer claimed, so Dr. Arthur Montgomery and Ed Over decided to file a claim on the Tooele County property. These two enthusiasts—one a scientist, the other a skilled mineral digger—established the Little Green Monster Mine and spent the spring and summer of 1937 digging in hopes of finding a quantity of septarian nodules. What they found was far beyond their hopes. They hit a wonderful seam of nodules and proceeded to extract tons of specimens of varying quality and size. The tunnel they dug to follow the nodule-bearing zone was so productive they had to carry the nodules out in a wheelbarrow. They continued to mine the property very successfully for a couple of years before deciding the mine had hit borrasca, apparent dead ground.

The Fairfield, Utah, septarian nodules are suitable for lapidary uses such as sphere making.

The variscites found by Over and Montgomery in Clay Canyon are certainly the most beautiful of all the varscites found in the West. Composed of a variety of minerals, these valuable concretions formed in sediments laid down by waters that covered the land millions of years ago. This particular deposit was blessed with a rich source of the phosphate radical, most likely the remains of early life buried in the original mud. This made possible the considerable variety of phosphate minerals—more than a dozen of them—that contribute various colors to the overall mass, which is dominated by shades of green variscite.

The rounded masses of green variscite found in Clay Canyon are prized by both the lapidary and species collector. The intense green color of the hydrous aluminum phosphate variscite—especially when contrasted by bright-yellow crandallite, a hydrous, hydrate calcium, aluminum phosphate—is very eye pleasing. These two phosphate minerals form the solid interior of the nodules, and their colors make wonderful cutting rough. Other species found in many of these nodules create a multicolored pattern; black to gray wardite stands in high contrast to the other colors, especially when it occurs as oval to round "eyes" in the green groundmass.

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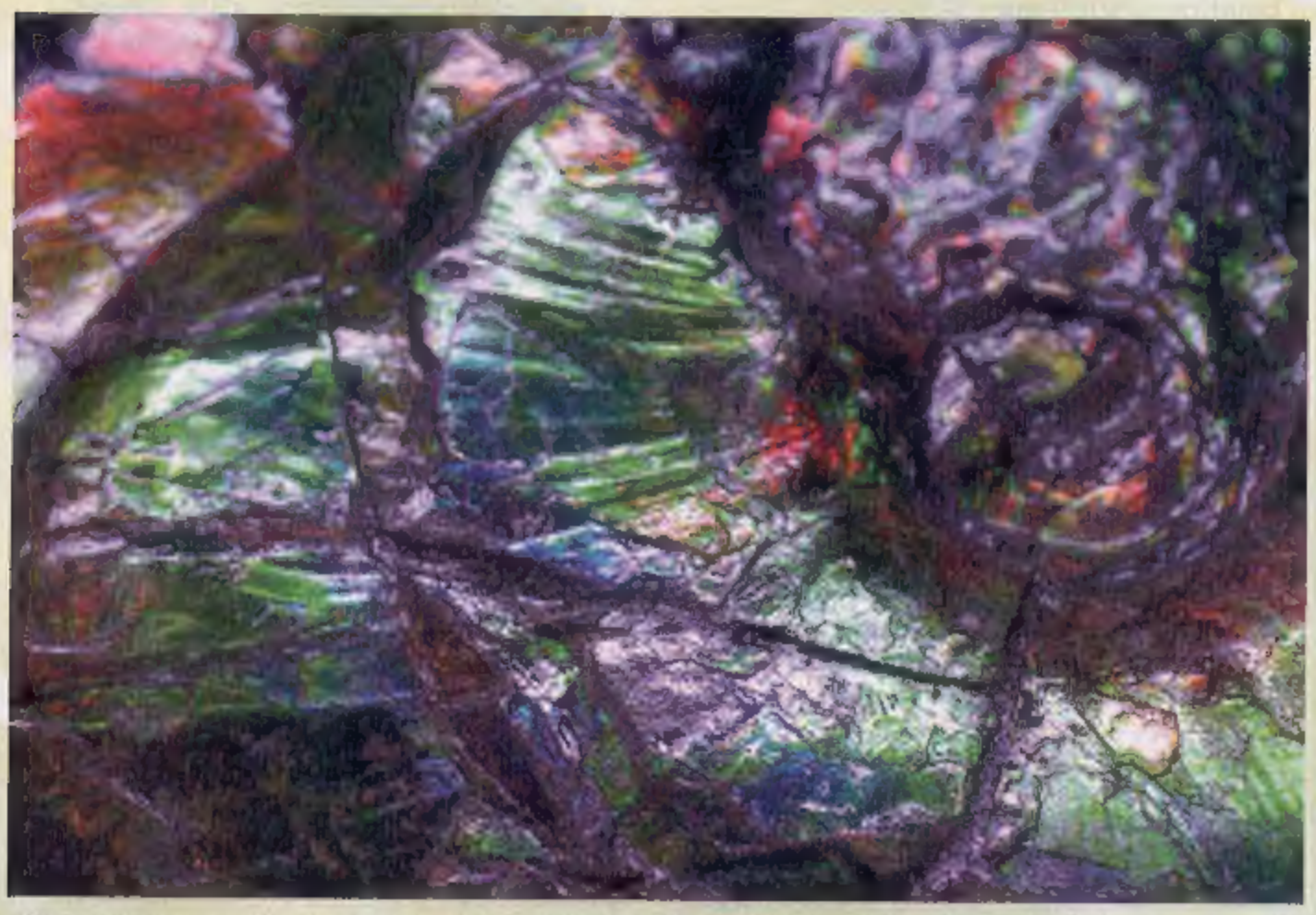


The amazing ammonites found in septarian nodules in Canada sometimes show a wonderful rainbow of colors.

Septarian Nodules *from page 21*

In the Fairfield nodules, one or more species developed as colorful linings, space fillings, and even small stalactites or projections in the bodies of the concretions. When a nodule is cut open, the interior may reveal a riot of color, often divided by thin lines of contrasting minerals. Projections that may have formed, if cut across the long axis, provide interesting, banded "eyes" of rare minerals like wardite and other species. Small openings provide space for minute crystals, some of which are quite rare.

Scientists have identified more than a dozen species in the nodules, some of them new. Two of these rare species have been named overite and montgomeryite after our doughty diggers of 1937. Because of the lovely colors and patterns seen in the Fairfield variscites, Dr. John Sinkankas calls them "One of the most beautiful of all North American gemstones"(*Gemstones of North America*, Vol. I, Van Nostrand Reinhold, 1959).

Other Utah deposits of variscite—near Lucin and on Amatrice Hill—have been worked. While these phosphate sources produce solid nodules that are suitable for cutting, they lack the variety of other phosphate species found in the Fairfield nodules.

ELK CREEK, SOUTH DAKOTA

Another source of septarian nodules is the Elk Creek area of South Dakota, which yields wonderful specimens of amber-colored barites. Some of the barites are so fine they yield choice faceting material for the gem cutter. For the collector of fluorescent minerals, the Elk Creek fluorescent barite/calcite combination is stunning.

The gray nodules are found abundantly in the Pierre Shale formation, a long, curving formation that actually extends into Montana and is cut through by Elk Creek. Calcareous concretions occur randomly throughout the formation, but seem to be somewhat concentrated in the area around Elk Creek in southwestern South Dakota.

The Elk Creek area is, by far, the most important source of these barite-rich septarians. The creek has exposed the randomly formed concretions, which can be seen weathering out of the high, sloping banks of Elk Creek. These concretions tended to form around the remains of ancient sea creatures. Some of the creatures were preserved as fossils in the concretions. The best of these fossil remains are ammonites, some of them still partially covered by the original nacre shell, not unlike the colorful interior of certain sea shells. The nacre typically reflects light and separates it into various colors, which gives these ammonites a delightful, iridescent color array.

As the sea receded, the rounded lumps of mud slowly dried out and developed cracks. Later solutions invaded these cracks, slowly precipitating a calcite lining along the surfaces of any openings. As the environment changed, so did these calcite linings.

You may recall that calcite and aragonite are paramorphs, meaning they have the same chemical composition, but different crystal structures. Calcite is hexagonal-trigonal, while aragonite is orthorhombic. The calcite linings of the nodule cracks changed from the original calcite

The Elk Creek, South Dakota, septarian nodules often yield superb, gemmy, amber-colored barites that also fluoresce.

crystal form to that of aragonite. The calcite paramorph aragonite forms the thin brown lining seen now between the walls of the nodules and the later-forming yellow calcite crystals. According to *Geodes*, it is this thin brown *septum* that is the source of the nodules' name.

As the calcium carbonate linings changed, additional calcite-rich solutions started depositing lovely yellow calcite, which crystallized as small, tapered prisms completely covering and lining any openings in the septarian nodules. These calcite crystals are seldom large, usually under an inch, and show a rather odd, curving structure. This colorful calcite alone makes these former mud balls quite handsome, especially since the yellow calcite fluoresces and phosphoresces under ultraviolet light. It also provided a perfect setting for the stunning, lustrous, often gemmy, amber-brown barites that

ter crystallized in the nodules. For such perfect crystals to form, the nodules had to rest completely undisturbed during the crystallization process.

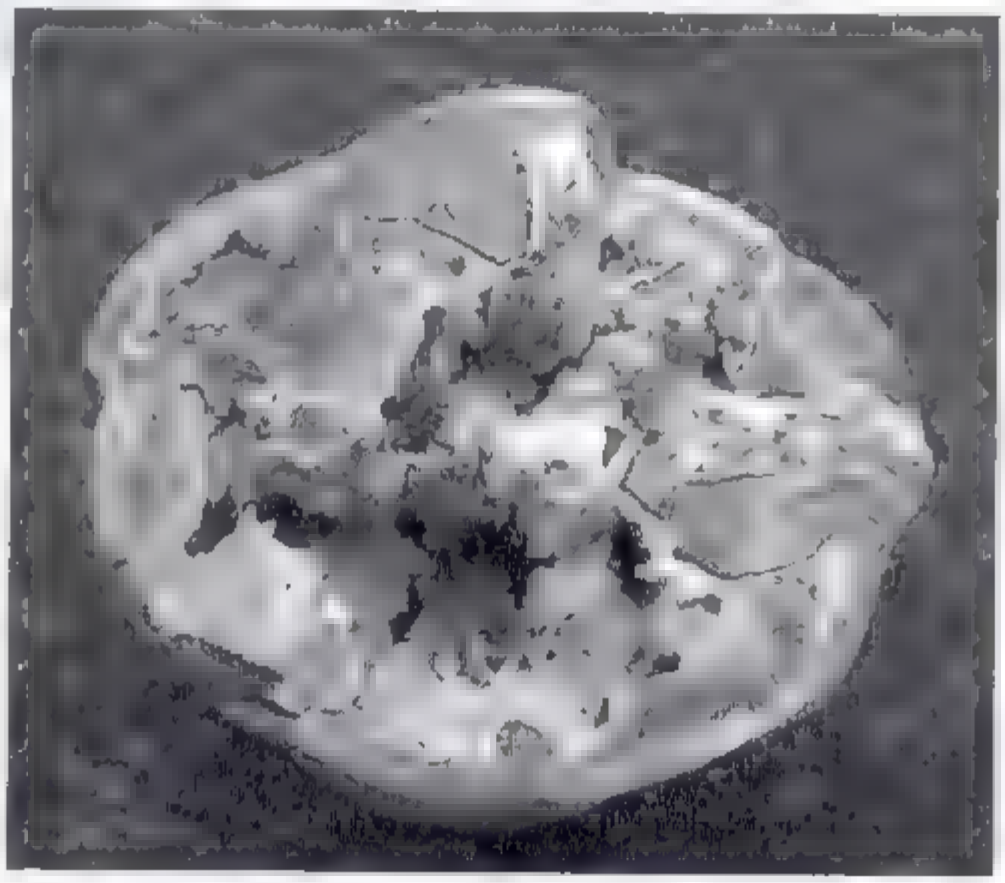
The Elk Creek barites are usually an inch or so long, but some crystals a foot long have been reported. Six-inch crystals are uncommon, but sometimes encountered. The crystals may lie flat on the calcite lining or stand free, either as individuals or in small clusters. They are very prismatic, several times longer than their cross section size, which is often under ½ inch. Many of the barite crystals show carving prism faces, which make them look fat. The crystal faces also usually show growth hillocks, striations, and multiple growth patterns, yet they often retain a brilliant luster. In cross section, the barites are square, typical of this orthorhombic mineral.

Mining these calcite/barite specimens is not easy. The nodules that were once on the surface have long since been collected, so digging in the shale is a must unless recent rains have exposed a few rounded balls. Once a nodule is found, it has to be carefully cracked in hopes it contains fine specimens and the barite. The nodules are often hard to break, and since barite has a perfect cleavage across the crystal, there is a risk of knocking the crystals off their perch on the calcite. Most specimens have one or more repaired crystals on them. Superb examples of the Elk Creek barites, which were once referred to as wine-colored, may be seen in many museums and private collections.

The Elk Creek area had been mined early on by collectors and more recently under collecting agreements with local ranchers, who often discourage random collecting and digging. The nodules were first discovered probably in the 1800s, brought near the surface by ground movement and erosion. The early mineralogy text *System of Mineralogy*, 6th ed., by James Dwight Dana (Wiley and Sons, 1959) describes "wine-colored barites in the Badlands of South Dakota in fossils" (p. 904). It was natural to assume these nodules were fossils because the formation of concretions was little understood and because many were found containing fossil remains.

MAZON CREEK, ILLINOIS

Located southwest of Chicago, in several counties west of the city of Kankakee, the Mazon Creek area of Illinois is rife with fossil concretions. The concretions are found widely scattered about this entire area, and you can expect to find them anywhere the earth has been disturbed by coal mining, construction, road building, and the like. The Mazon Creek area is particularly rich in the concretions because it is a delta-type area where sand and gravel from upriver were deposited extensively millions of years ago. Formed in the Pennsylvania period of the Carboniferous Age, the ancient delta was the outwash deposit of river sediments that were carried south and dumped into the inland sea that covered the entire Midwest at the time. Like so much gravel, the concretions were carried along until the flow of water slowed.



Many septarian nodules have a really fractured interior due to shrinkage of the original mud ball.

The concretions in the Mazon Creek area are a study in early land, swamp and sea fossil life, both plant and animal. Bacteria associated with the life debris created a hard zone, which enclosed the concretions and preserved the fossils inside. The variety of life found in fossil form here is amazing. At least 400 plant species have been identified, along with more than 300 species of land, sea and swamp animals. The Illinois state fossil, the *Tullimonstrum gregarium*, was found in a Mazon Creek concretion. It is an odd creature that is still being studied.

One of the nice things about the Mazon Creek area is that it is large enough that private collecting is still possible. A common collecting technique is to scour through the chat piles and dumps created by mining and construction along the banks of the creek. That sure saves a lot of digging!

The Mazon Creek fossils hold myriad remains of early life dating back some 300 million years. At that time, the region was a vast swamp and, due to continental drift, was actually near the equator. It was quite warm, plenty moist, and ideal for the growth of plant life. With plant life comes lots of animal life, both on land and in the swampy waters and nearby warm seas.

The nodules are an interesting study in themselves. They can be various shapes, but the dominant shape is a long, tapered form rather like a distorted egg. What allows these shapes to survive is their hardness compared to the rock in which they formed, thanks to those early bacteria. This hardness enabled the entire mass to survive as it was tumbled and tossed before ending up in the ancient river delta.

The best known Mazon Creek fossils are the lovely fernlike leaf fossils found when elongate concretions are split lengthwise. Their patterns are a nice, contrasting darker brown or black against the nodular mass. Several varieties of plants bore such fernlike leaves 300 million years ago, tree leaves as we know them had not yet developed. The more common variety of fern fossil found at Mazon Creek is probably the Pecopteris type seed fern, which differs some from true ferns that also grew there. These leaf fossils are commonly offered for sale at shows and open-air markets.

The animal fossils at Mazon Creek are considerably less common. After all, plant life was far more abundant in a warm, moist swamp, and dead animals tended to become a meal for a scavenger. Still, wonderful fossil remains of worms, jellyfish, fish, amphibians, and dry-land creatures like scorpions, centipedes and insects can be found.

ALBERTA AMMONITES

The most attractive fossil remains obtained from concretions are ammonites from Alberta, Canada. The popularity of these ammonites may simply be due to diligent mining and good marketing, or they may be more attractive than similar ammonites from the Pierre formation shales; I cannot say since I have not been able to compare the two. In any event, the ammonites from the Alberta region are fine gem material and are used in jewelry.

continued on next page

Septarian Nodules *from page 23*

Ammonites are a type of cephalopod that lived millions of years ago. We are most familiar with the coiled type that emerged during the Paleozoic Era and continued into the Age of Dinosaurs. These sea creatures eventually became extinct toward the end of the Cretaceous period, at the end of the Age of Dinosaurs. Today, the seas yield their descendants, the octopus and squid.

The ammonite built its shell out of small plates of aragonite, extracting the calcium and carbonate radical from the seawater in which it lived. These substances combine with others to form nacre, the iridescent lining we see in shells and call mother-of-pearl. Most ammonite shells we find today have been replaced by rock and are a dull brown or tan. The exceptions are some found at Elk Creek and in Alberta.

We find ammonites that have been replaced by iron pyrite in Ohio, Germany, Siberia and a few other places. These lovely fossils can be polished to highlight the brassy yellow pyrite. They can also be sliced in half to reveal the repeating chambers, usually now filled with mineral matter. When the ammonite was alive, these chambers were filled with air to add buoyancy to the animal as it jet propelled itself through the ocean.

Two varieties of ammonite are found in the Bearpaw and Pierre shale formations near Lethbridge, Alberta: the *Placenticeras intercalare* and *Placenticeras meeki*. These ammonites are found in ironstone concretions, scattered randomly in the shale formations. Large amounts of useless surface material have to be moved to find the concretions.

The marine shale in which these colorful ammonites are found resulted from an arm of what is now the Gulf of Mexico which extended all the way up through the western North American continent and connected to the Bering Sea long before the United States came into being.

These unique and very attractive ammonites were first reported around 1913. Commercial mining began in 1969, and they are currently being mined for their gem value. These colorful ammonite gems are quite easy to identify. Their color is usually a vivid red, orange or green. You can often see the small nacre bits, especially with a hand lens. The larger surfaces will usually show dark lines, which result from the surface material having been lightly crushed, separating the sections of iridescence. Still, the overall effect is quite colorful and attractive.

As the fossilization process proceeded, the original shell of the ammonite, instead of being replaced by dull, bland, granular stone, was preserved. The outer

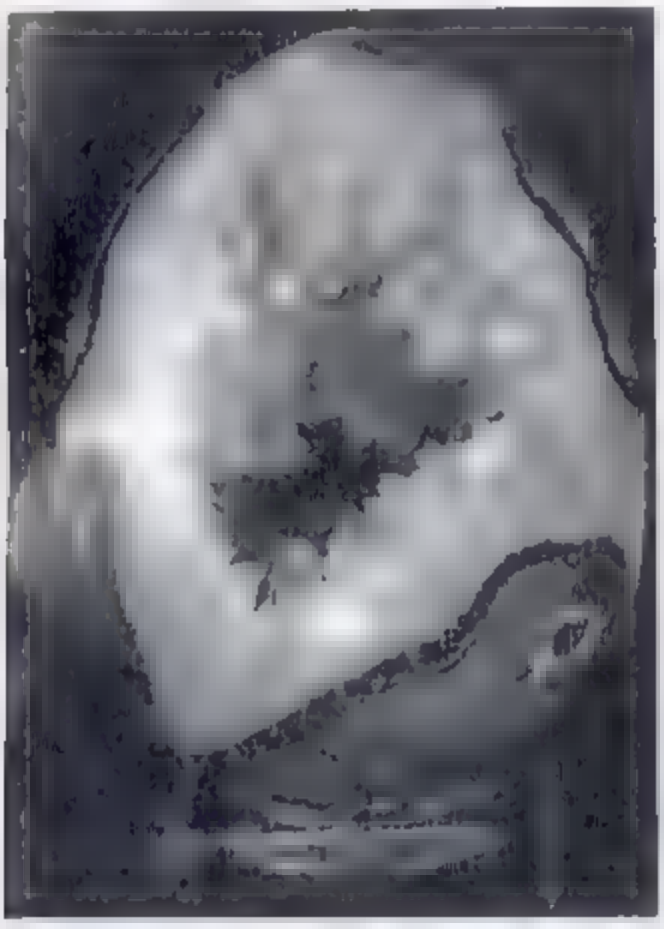
A pyritized ammonite in the center of a septarian nodule is a rare find

shell, which consists of nacre, was preserved as the mineral aragonite, the paramorph of calcite. Nacre is a form of aragonite that crystallizes as tiny hexagonal plates, which stack on each other to form something resembling a diffraction grating. These tiny nacre plates have a diffraction grating effect, separating light into its component wavelengths so that the viewer sees all the colors of the rainbow reflected back as flashes. The color patterns change when the shell is moved, just as in opal. The nacre shell is mainly aragonite with a trace of several elements like strontium and copper. It also contains conchin, an organic substance found in many sea life remains.

The nacre layer is extremely thin, but fragile as it is, it can be worked into jewelry. Cabochons have to be done in doublet or triplet form to strengthen the gem, and are readily available under the commercial name ammolite. When it was first investigated as a gem material, ammolite was found to contain hydrocarbon inclusions, which caused instability in the material. Experiments were made to purge the hydrocarbons and stabilize the gem. They were apparently successful, as good material is readily available at shows now.

GRAND JUNCTION, COLORADO

Another type of collectible septarian nodule with very attractive crystal specimens is found in the Book Cliffs area north of Grand Junction, Colorado. If you ever drive through Grand Junction on Interstate 70, you'll be impressed with the number of oil-gas wells all along the highway. The region is an important producer of these natural energies. The



This septarian nodule was shaped into an egg to expose a calcite vug inside.

deposits occur in largely sedimentary rock formations, one of which is a calcareous clay, in which calcareous sandstone concretions occur. When the Book Cliffs erode, the concretions are freed. Some of them are as large as 15 feet in diameter.

The cracks in these concretions were filled by barite rich solutions. Many of these septarian nodules are hollow in the center and sometimes they contain no crystals, but a few are rich in lovely, colorless, water-clear barite prisms that have a square cross section and a chisel-point termination. The crystals range in size from microscopic to as much as 6 inches long. They are slender, often no more than ½ inch across. They are usually flawless, and the prisms are smooth faced, seldom showing any surface hillocks, striations, or growth patterns.

Collectors must take care when breaking into these sandstone masses. The barite has perfect cleavage, any sudden shock, as from the blow of a sledgehammer, could cleave the crystals inside. Some crystals are already off the matrix when a nodule is opened. Others are attached, usually as a single prism with one or two minor prisms attached around the base.

Many of the Grand Junction concretions have no crystals in them, which highlights the earlier question. Are they just concretions if they lack crystals, while their crystallized brethren in the same zone deserve septarian nodule status?

ORDERVILLE, UTAH

Between Zion National Park and the recently established Grand Staircase Escalante National Monument is the town of Orderville, Utah. The major rock formations of this entire area are sedimentary: impressive, more-or-less-horizontal layers of sandstone, shale, and the like. The formations are colored in large part by iron oxide, and weathering has carved them into marvelous shapes. This region was not always the dry, desertlike environment it is today. Over 100 million years ago, the Gulf of Mexico extended like an arm right into the southern Utah region. Mud accumulated on the sea floor here, creating ideal conditions for the formation of mud balls that might develop later into concretions or septarian nodules. Today, superb septarian nodules can be found at a depth of 5 to 10 feet. The nodules can be exposed by either digging into the layer in which they are found or tearing away the overburden by mechanical means.

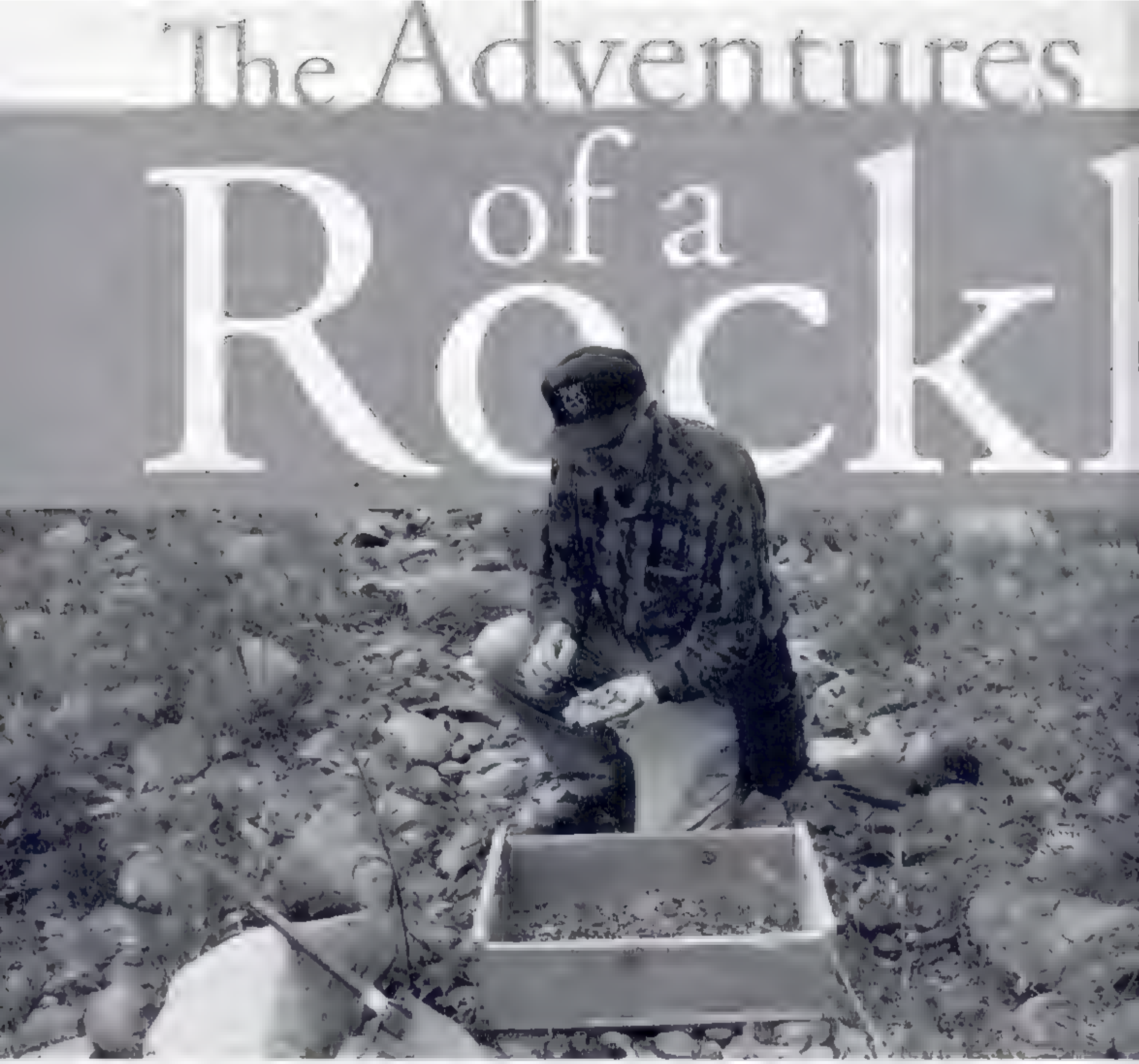
The Orderville nodules were invaded by calcite-rich solutions, which formed calcium carbonate crystals. The initial calcite coated the interior of the nodules' cracks, as at Elk Creek. This calcite later transformed into a brown layer of crystalline aragonite, calcite's paramorph. Another invasion of calcite solutions developed into lovely yellow calcite crystals on the earlier calcium carbonate layer.

Because the shrinkage of these masses was so great, there were large openings and wide seams in which the calcites could develop. The crystals are never large, but they line the openings completely. When cut properly, these septarian nodules will show wonderful, crystal-lined cavities that look like miniature caves.

Since most of the Orderville region is being commercially mined, a stunning assemblage of wonderful display objects are being produced. Skillful trimming and machine work enhance the natural product. At gift shops or mineral shows, you can find large eggs with perfectly centered, calcite-filled openings. Some are carved into bear or buffalo silhouettes, again with a calcite-lined opening perfectly centered. Geodelike shapes are cut from the smaller nodules. The contrast among the dark-brown nodule, the amber-colored septa, and the bright-yellow calcite lining of crystals is exceptional.

While concretions are quite common, fine septarian nodules that yield choice crystal specimens are really uncommon. Whether you dig your own or purchase a commercially prepared specimen, a septarian nodule is a beautiful specimen suitable for display. What more can a rockhound want?

The Adventures of a Rockhound



Stories from a Lifetime of Collecting

Story and Photos by Kenneth H. Rohn

As a dyed-in-the-wool rockhound, I spend a good deal of time staring at the ground. No matter where I go, there's always the possibility that I might discover a gemstone that others have tread upon without knowing it, and that has actually happened on rare occasions. Naturally, I take time out to get my bearings and admire the scenery, as well, but when in the field, collecting is almost an obsession with me. I actually love the hobby of collecting rocks, and I've been doing it since I was 5 years old.

I remember one incident that happened when I was a youngster. I had been out on a very adventurous field trip in the vacant lot across the street from our home. I gathered a wonderful collection of pretty rocks and emptied the contents of a bulging pocket—including, I imagine, an accumulation of dirt—onto my dresser next to the bed. As I think back, those rocks were nothing more than granite and perhaps sandstone pebbles, with possibly a few nubbins of shale mixed in, but they were important to me at the time.

After school one day, I went into my room to admire my rocks. They weren't there. I remember running to Mother and mentioning the fact that my rocks were gone. I raised quite a fuss about them. Mother confessed that she had put them away. When I asked where they were, she

nound

The agate mine at Thunder Bay, Ontario is one of few sites that contains agates in situ, including huge boulders with agate veins.

Fairy crosses can be collected at a number of easy-access locations along the Mississippi River.

smiled rather sheepishly and said they were outside in the driveway She had tossed them out. After all, they were cluttering up my room Mother and I laughed about it on occasion for a good number of years.

Well, I recovered from that incident long ago, but I have never recovered from the habit of collecting rocks. It sometimes pays huge dividends to direct one's attention to the ground around us. A case in point Not that many years ago, a lady was out for her constitutional in Craig, Montana I'm certain she was enjoying the beautiful day. As she walked along a secondary road, something caught her attention glistening on the shoulder She picked up a shiny rock that happened to be a flawless pale-yellow diamond weighing 14 carats This perfect oval diamond sold for $80,000 to a New York man That was quite a stroll!

As we know, this is a hobby that induces vigorous health. One exception, of course, is the fact that it doesn't encourage good posture I recall a humorous incident that happened to a friend, Professor Odenbach at the University of North Dakota. He once told me with a chuckle that some of his students were worried about him. It turned out that it was his habit during lunch break to scramble up and over the foothills near campus in a crouch, picking up something now and then When the students witnessed his antics from afar, and asked if they could be of help, he simply told them that he was looking for agates. Several days later, he overheard a student remark under her breath, "There goes poor old Professor Odenbach He has a back problem; you know what I mean?" and she raised her eyebrows knowingly

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During a day in the field, we tend to forget our everyday cares and woes, we're too busy searching for rocks. Our appetite improves and food always tastes so much better than at home. Sleep comes easily because we're tired, but it's a different kind of tiredness, a healthy kind.

Throughout the years, my continuing quest for collecting sites has taken me to many distant places and adventures. Sometimes quite by accident, I've stumbled upon fantastic gem-collecting locations, and of course, there are other times when just the opposite was true.

I've certainly had my ups and downs along the way. One time in Montana, the wife and I stopped next to the Missouri River. I parked on the shoulder, took my camera, and promised to be back shortly for the lunch she was fixing. I had spotted what I thought was a gravel bar near the highway and was going to check it out.

When I parked, I made certain that I was well off the road. What I didn't take into account, was the fact that someone was watching me. I walked along the shoulder of the road, passed under the bridge spanning the river, and proceeded down to the water's edge. Instead of gravel, I found a sandbar with no rocks at all present. I waved to a man fishing in a boat, took a few photos for my files, and returned to the camper.

Very shortly thereafter, there was a knock on the door. I opened it to see a lady scowling at me. I said hello. She introduced herself as the owner of the property, and asked me what I was doing parked on her land. I told her that I was down at the river taking photos.

The woman remarked that her children had been watching and said that I was parked there for the better part of the morning. Actually, it had been no more than 15 or 20 minutes. I told her that. She didn't believe me and announced that the farm equipment on the other side of the fence was theirs and they didn't like people to be here. I desperately wanted to point out that where we were parked was public domain, but instead I promised that we'd leave very shortly. There's no point in arguing with an irate landowner. She turned and walked across the highway, where she stood watching us. I could still see her in the rearview mirror when I crossed the bridge. The consequences of my adventure could have been severe, instead, they were only embarrassing.

Another time in my home state of Minnesota, I was searching for a way to reach a public beach. I was told that I'd find good collecting there, but I failed to get the proper directions from a passer-by. The road map that I studied indicated that a secondary road should lead to the beach of this small lake.

I turned off the highway and entered what I thought was the secondary road. As I drove slowly onto the property, I began to realize that this wasn't a public road. Just then, a huge diesel payloader came rushing up out of nowhere and stopped a foot from my bumper. The bucket was pointing right at my windshield. The driver leaped out of the machine and approached my vehicle, angry as all get out. He told me to get off his property pronto, and made a remark about ignorant tourist trespassers. When I tried to apologize, he ignored me and repeated that he'd like me off his property very quickly. He did not move the payloader and I had to back up for quite a way before I could turn my pickup camper around and leave.

The Blanchard Dam, on the Mississippi River near Royalton, Minnesota, is a dramatic backdrop for fairy cross collecting.

I never did find that beach. I learned later that the property had been purchased by a private party and the beach road was closed. I also learned that I was on the wrong side of the lake. That was one time I didn't continue to follow up the lead to a conclusion.

Of course, those negative experiences tend to teach us to make certain that we have done our homework before entering any potential collecting site. Also, courtesy should always be our Number 1 priority. Occasional irresponsible acts by a few reflect greatly upon the majority in our hobby. The landowner is right, no matter what, even if we know for certain that he's wrong.

Then there are the positive situations, in which I've encountered landowners who actually have welcomed me with open arms. One incident happened in Kentucky several years ago. We were looking for a place to hunt for geodes, as I had learned from research that this area should have an abundance of them. The only problem was that we didn't know anybody in the area or where to go.

I walked into the Chamber of Commerce, told the lady I found there what I was looking for, and asked her if she could help. In a matter of minutes, I was on the phone with a local rock shop owner. Ed turned out to be a life-long friend. He treated us like royalty and took us to a very prolific collecting site on a farm in the hills. The lady farm owner was very happy to have those troublesome geodes removed from her field. It so happened that there were literally dozens of them scattered all over along the creek banks on the property. We had not only gained a very good friend, we had one of the best field trips imaginable.

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My rockhounding adventures have taken me to far-flung places to collect.

Any prolific collecting site can soon become exhausted. Most of the surface material the easy pickings is soon gathered up. If the site is a large tract of land, the easily reached areas close to the road will be picked over first. The more difficult the site is to reach, the more likely we are to find a bonanza. It often pays to go just a bit farther afield. It will be a job carrying out our specimens, but the effort is usually worthwhile.

There's nothing more frustrating that I can think of than to arrive at a destination a great number of miles from home only to find that there's literally nothing to collect and no access to the supposed site. This has happened to me (and I'm guessing that it's also happened to you) more times than I care to acknowledge. I have always taken great strides to make certain that the information I give to readers is up to date and as accurate as I can make it. The only possible way that this can be done is to visit the site personally before sending others there. With the phenomenal price of gasoline today, it can be a costly proposition.

One solution we have to this growing dilemma is fee mining. As a rule, the places at which I paid a fee to collect were as advertised, and I went away with a feeling of accomplishment and a nice collection of stones for my efforts. The drawback, however, is that fee-collecting sites aren't as plentiful as one would expect. They are out there, though, waiting for us to find them.

A fee mine that I particularly enjoyed visiting recently is Sheffler's Geode Mine, located near Wayland, Missouri, a small town adjacent to the Mississippi River. While at this mine, I managed to dig and collect a rather nice selection of geodes that were buried in the clay of their pit. It was a fantastic day.

Some sites keep replenishing themselves year after year. Spring runoff in Montana rivers, particularly the Yellowstone and her tributaries, overturns fresh material and moves it to the surfaces of the numerous gravel bars. Of course, this action always depends upon the amount of winter snowfall in Montana.

I've seen the Yellowstone River during spring runoff, and it is a most impressive sight. It would not be wise for anyone to attempt floating a boat on such turbulent waters, to try to walk across to a gravel bar would be disastrous. I have seen boulders, some the size of basketballs, being pummeled about like pebbles in the maelstrom of water as it rushed downstream with the force of a locomotive.

If you're investigating a new site, secondary roads, road cuts, and embankments are often good places to get an idea of what you might find in the area, but before you do any collecting on them, make certain that this is allowed. I've had bountiful success doing this on several occasions.

Upon discovering selenite crystals sparkling in the sunlight on one embankment adjacent to Bureau of Land Management (BLM) property, I went inland a way and not only found selenites of good quality, but numerous beautiful, purple barite crystals the size of walnuts resting on one eroded embankment.

Even when we do our research, the site in question may not always prove productive. A case in point was Frying Pan Basin in Wyoming. This is a huge tract of land regulated by the state BLM. I did a wealth of research on the area and I learned that the potential for finding large silicified logs was good. This alone was an incentive to visit the place.

Hobbyists are allowed to remove 25 pounds of petrified wood a day, plus one piece, from BLM land. There is no specification of how large that one piece can be, but common sense tells us that it will be small. A petrified log of any size can weigh a great deal more than 25 pounds, so anything this large is off limits, unless we acquire a special permit from the state.

While in Wyoming, I looked up and talked with one of the rangers of that district. He told me that I would be lucky if I found anything because the land near the highway had been literally picked clean of wood. When I visited the site, I soon learned that he was right. I did manage to find a few colorful pieces that had been overlooked by others. The ranger had mentioned that there is vast potential still hidden beneath the surface, but who knows how long it will take before erosion exposes fresh material?

Frying Pan was a very prolific, easy-access collecting site, but to my knowledge it no longer is worth the effort or expense to visit the place, as far as collecting is concerned.

As the seasons have passed, I've leaned more and more toward fee mining and collecting sites. This is one way to ensure a successful field trip. You arrive at a pre-planned, reserved location, pay a nominal fee, and practically have the place to yourself. You can enjoy the thrill of being able to collect the prescribed gemstones or rocks without any hassle. A good deal of information on potential collecting sites can be obtained by reading *Rock & Gem* magazine and other reliable literature relating to our hobby.

While you're out in the field staring at the ground in search of precious gemstones among the millions of rocks and pebbles at your feet, take time out to look up once in a while to enjoy the scenery around you. Carry out what you've brought in and put your best foot forward. It pays big dividends.

Rock Science

by Steve Voynick

Sea-Bottom Sulfides

During the 1960s, the sea-bottom mining of manganese nodules seemed to have great economic potential. Countless millions of these nodules, which consist of minerals precipitated from seawater, cover many parts of the ocean floor and contain, on average, 30 percent manganese, 6 percent iron, 1 to 2 percent nickel, and lesser amounts of copper and other base metals. The biggest profit incentive for mining these nodules was nickel, which was then scarce and costly. During the 1970s, however, big, new Soviet and Canadian nickel mines began glutting metal markets and ocean mining was forgotten.

Now, mining geologists are again turning to the oceans, but not for manganese nodules. This time it's for seafloor massive sulfide (SMS) deposits that are created by hydrothermal vents called "black smokers." Black smokers are the active vents of large, sub-sea-bottom, thermal-circulation systems that are powered by the heat of deep magmatic bodies. Black smokers occur worldwide along the boundaries of tectonic plates. Their associated SMS deposits consist of chimneylike structures and adjacent sea bottom layers made up of highly concentrated metal sulfides.

Black smokers were only discovered in 1975, but marine-mining companies have begun investing millions of dollars in exploration in the hope that SMS deposits can be mined for base and precious metals.

The thermal circulation systems that create black smokers and SMS deposits form when cold seawater percolates down through the sea bottom. The water eventually heats and circulates via convection toward the center of the vent system, which is located above a body of hot magma. As the water becomes hotter, it begins to dissolve sulfur and become acidic, enabling it to dissolve such metals as iron, copper, zinc, lead and barium, along with lesser amounts of cobalt, nickel, silver and gold.

This metal-laden hot water subsequently moves upward through pore spaces in the sea bottom substrate. As it rises, it creates voids and fissures, and eventually forms an open pipe just before venting into the cold seawater.

By then, cooling has already caused some dissolved metals to precipitate out of solution. Most copper and gold falls out in the passages immediately beneath the seafloor vent, while iron precipitates as pyrite (iron disulfide) at the base of the vent.

The chimney-shaped structure that builds up around the vent is composed primarily of galena (lead sulfide), sphalerite (zinc sulfide), barite (barium sulfate) and anhydrite (anhydrous calcium sulfate). When the hot, mineral-laden water vents through the chimney into the cold seawater, its remaining mineral content instantly crystallizes as a "flash precipitate," a cloud of black, metal-sulfide particles from which the black smoker gets its name. These sulfide particulates quickly settle to the bottom as a layer of metal-rich "exhalite."

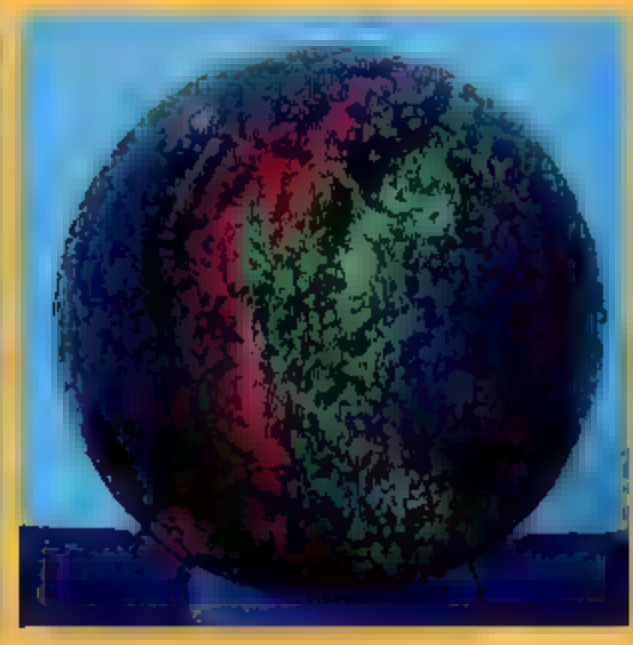
Although the metal grades of SMS deposits vary, they are generally much higher than those of conventional ores. A section of one black smoker chimney recently recovered near Australia from a depth of 6,000 feet was nearly pure sphalerite. Consisting of 50 percent zinc by weight, it is 10 times richer than the best zinc ore mined on the surface today. Another SMS sample, this one recovered near New Zealand, assayed to 10 percent copper, along with 1 troy ounce of gold and 17 troy ounces of silver per ton.

Marine scientists have mapped thousands of SMS deposits along the world's tectonic boundaries, almost all at depths greater than 5,000 feet. Most deposits are relatively small, but a significant number are large. Containing millions of tons of SMS mineralization, they have far greater economic potential than the manganese nodules had in the 1960s.

Mining geologist and leading SMS researcher Dr. Steven Scott of Canada's University of Toronto notes that most high-grade, easily accessible mineral deposits on land have been found and the time is right for mining companies to take a closer look at SMS deposits. "Some are seeing that it is a lot easier to go down through a couple of thousand meters of water," Scott says, "than through a couple of thousand meters of rock."

ROCK & GEM

What Is Ultraviolet Light?



What is ultraviolet light? For that matter, what is light? Scientists say almost all energy is electromagnetic radiation. The differences in wavelength and frequency give each type of energy its unique properties.

The visible light that our eyes use to see the world around us has wavelengths from about 400 to 700 nanometers (nm). A nanometer is a millionth of a meter, which is a pretty tiny measure! Red light has a wavelength of about 650 nm, yellow light about 570 nm, green light about 510 nm, blue light about 475 nm, and violet light about 400 nm. Light with shorter wavelengths, between 400 nm and 100 nm, is not visible to humans. We call this light ultraviolet (UV) light.

If we can't see it, how do we know it is there? UV light has a big effect on life on Earth. It is powerful radiation and can cause sunburn, skin cancer, and blindness from cataracts if we are exposed to it long enough. Fortunately, a special layer of our atmosphere contains an unusual oxygen molecule called ozone that protects the plants and animals on Earth from this dangerous radiation.

UV light is well known to rockhounds because it can make some minerals glow in the dark. This phenomenon is known as **fluorescence**, and it can be used to identify certain minerals. Fluorescence has been used in prospecting for valuable ores of zinc such as willemite, and the major tungsten ore, scheelite. Clothing manufacturers put UV dye that glows blue-white into their white cloth so that the cloth looks bright white when lit up by the UV in normal daylight.

Long-wave ultraviolet light, or UVA, with wavelengths of about 315 nm to 400 nm, is closest to visible light. It is well known for its use in illuminating disco lights and psychedelic posters.

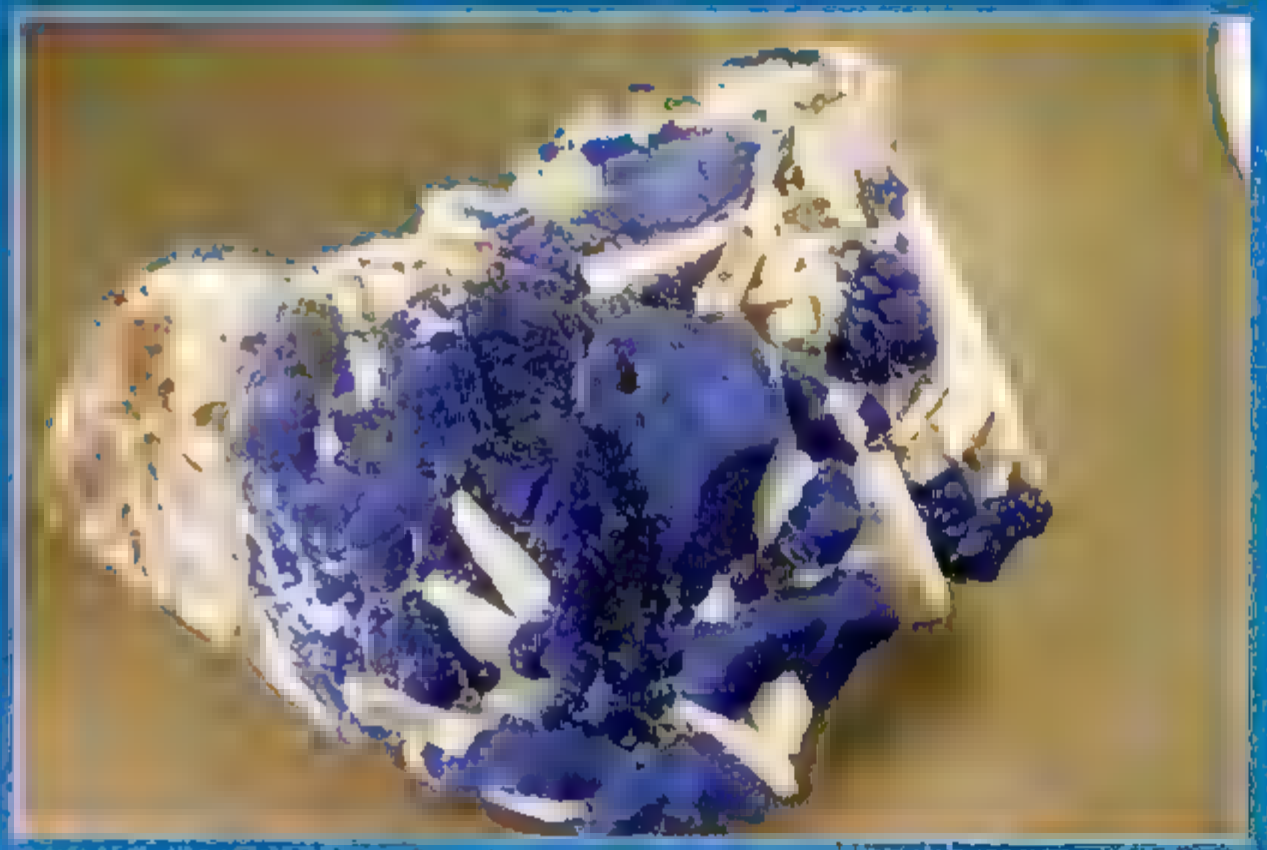
Medium-wave ultraviolet light, or UVB, has a wavelength of 280 nm to 315 nm. It will make some minerals glow that are not responsive to long-wave or short-wave UV. Minerals often fluoresce a different color under UVB than under UVA or UVC. It has only recently been discovered by rockhounds, so there is still a lot to learn about its properties in regards to minerals.

Short-wave ultraviolet light, or UVC, has a wavelength of 200 nm to 280 nm. It is the most useful for our purposes, as more minerals glow when exposed to this radiation than under UVA or UVB. Unfortunately, it is also more difficult to produce, and short-wave UV lamps are more expensive. UVC makes minerals display interesting phenomena such as phosphorescence (the mineral continues to glow after the UV light is turned off) and tenebrescence (the color of the mineral in visible light is changed by the exposure to UV light).

KIDS

by Steve Becker

Sodalite



Rock & Gem Kids Quiz

The *Rock & Gem* Kids Quiz contest is open to U.S. residents age 18 and younger. All these questions can be answered by carefully reading this column. Write your answers neatly on a postcard or 4X5 card and mail to **September *Rock & Gem* Kids Quiz, P.O. Box 6925, Ventura, CA 93006-9899.** Valid entries received by **Sept. 30, 2007** will be entered in a drawing from which five winners will be chosen. Valid entries must be the entrant's own work and must include the correct answers, the entrant's name, age and address, and the signature of a parent or guardian. Prizes are generously provided by the Arizona Mineral and Mining Museum Foundation.

1. The members of the sodalite group are _____, _____ and _____.
2. What happens to hackmanite when it is exposed to sunlight?
3. The property described in Question 2 is called _____.
4. What harm can UV light do to living things?
5. The oxygen molecule in our atmosphere that blocks much of the harmful UV radiation is _____.

GLOSSARY (Use your dictionary to look up other words you don't know.)

tenebrescence the ability of a mineral to change color when exposed to sunlight or UV light

massive made up of interlocking crystals without faces

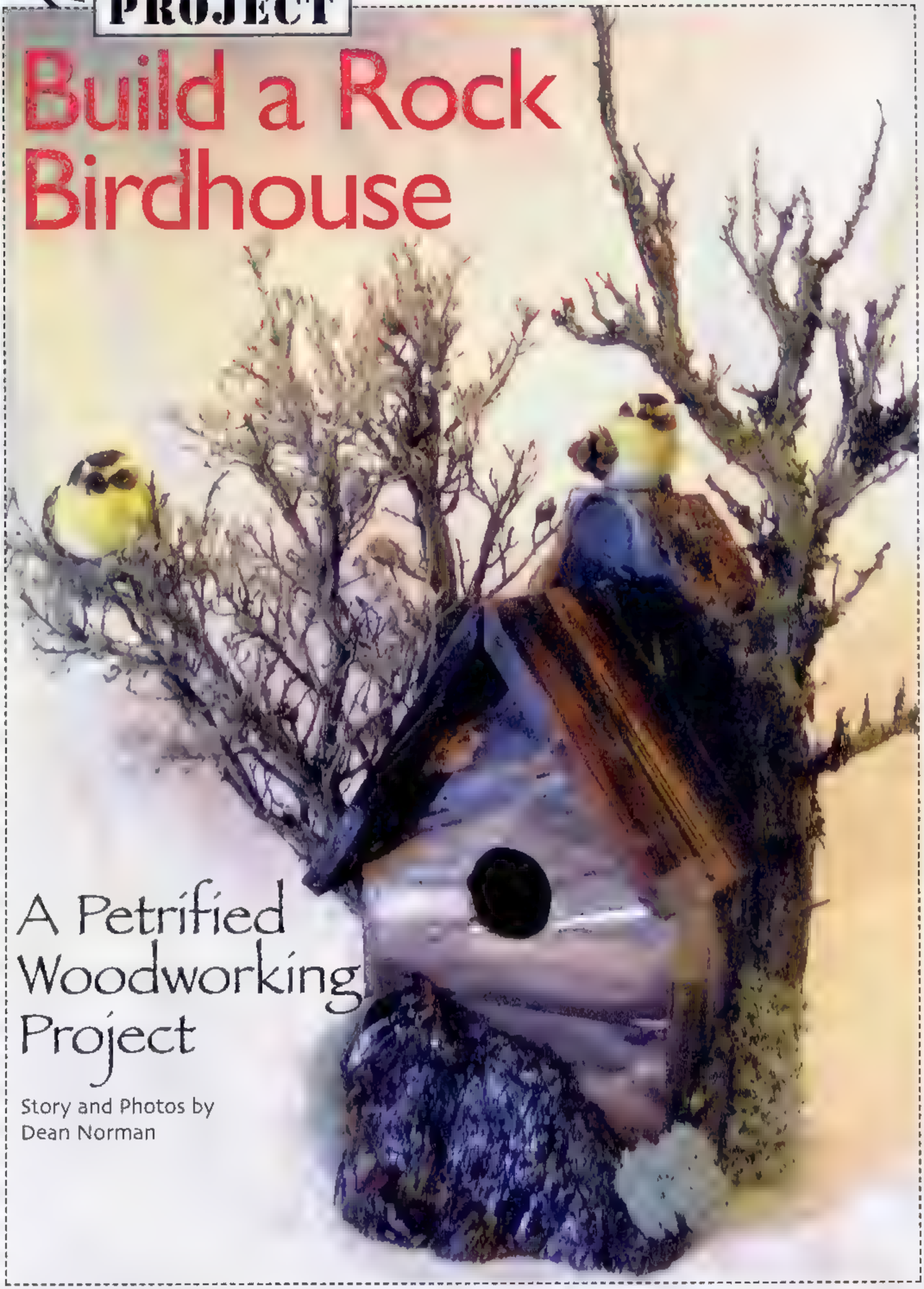
fluorescence the ability to produce light while being acted upon by ultraviolet rays and other forms of radiant energy

PROJECT

Build a Rock Birdhouse

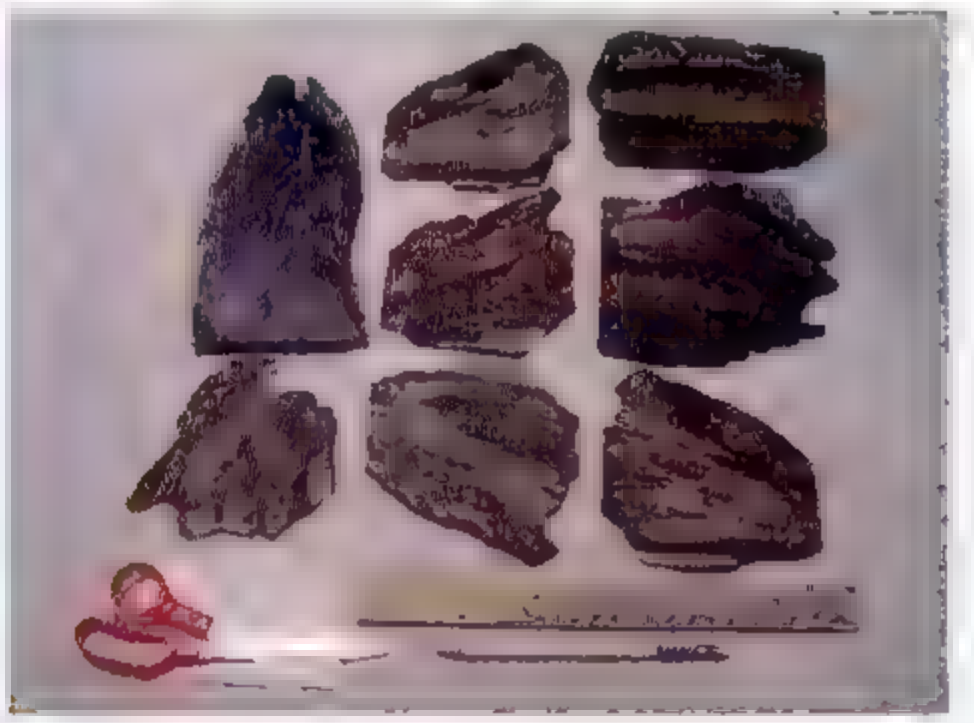
A Petrified Woodworking Project

Story and Photos by
Dean Norman



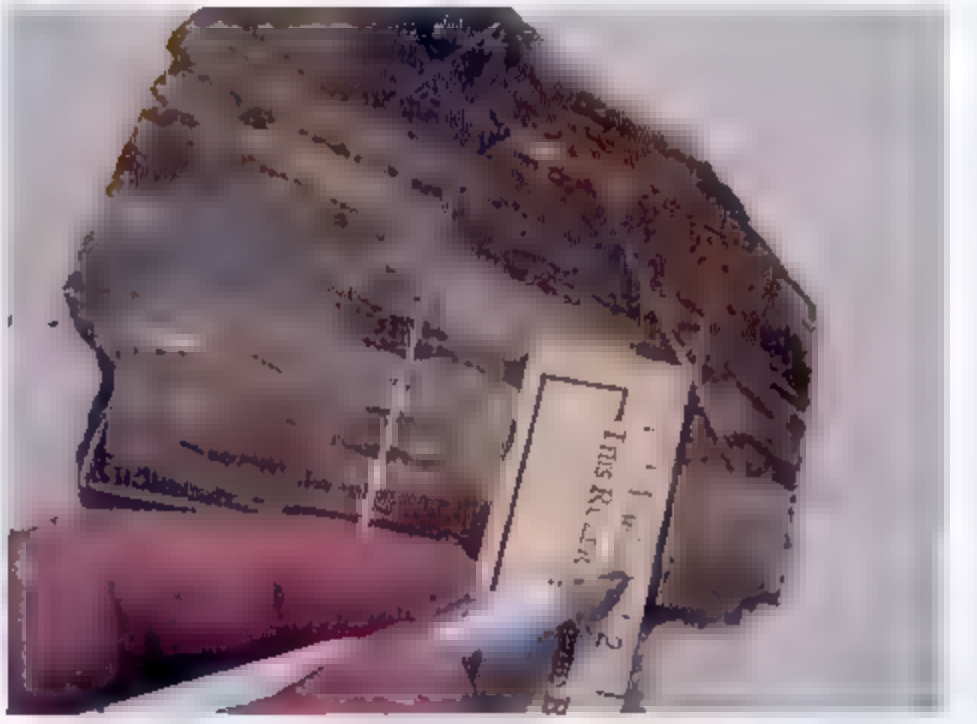
MATERIALS:
petrified wood
pencil
two-part 5-minute epoxy
Popsicle stick
2 large rubber bands
1 spray can of gloss lacquer
small artificial birds
dried moss
dried branches

TOOLS:
18 inch lapidary saw
1" x-men diamond hole saw
Dremel tool with small diamond bit
12-inch ruler
aluminum pencil
machinist's square

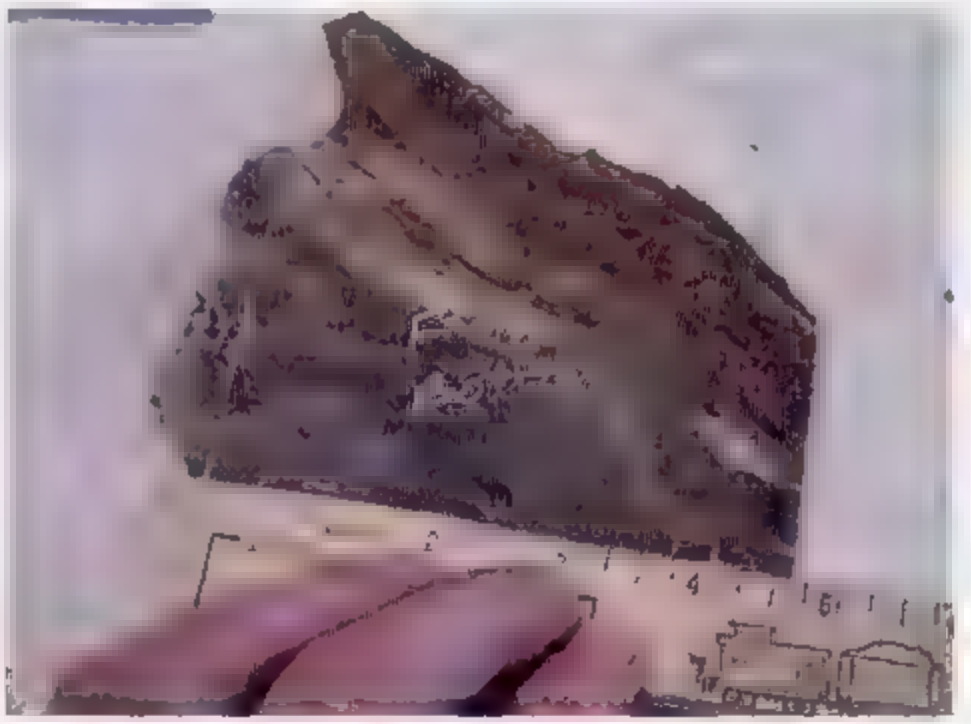


Pick out your wood and cut as many ¼-inch slabs as you can.

Measure and cut two roof slabs that are the same size



Measure and mark a 45-degree peak on the front slab.



Label your slabs with an aluminum pencil so you can remember which is which.

Make an angled cut in the top edge of each roof panel using the front panel as a guide.

Petrified wood is a fascinating rock found in abundance here in Washington, and it makes great birdhouses. Making a rock birdhouse sounds easy, right? Well, it's not as easy as one would think: a lot of thought goes into the structure. I build birdhouses for indoor use as decorative pieces, not for birds to actually use outdoors, but I suppose one could do that.

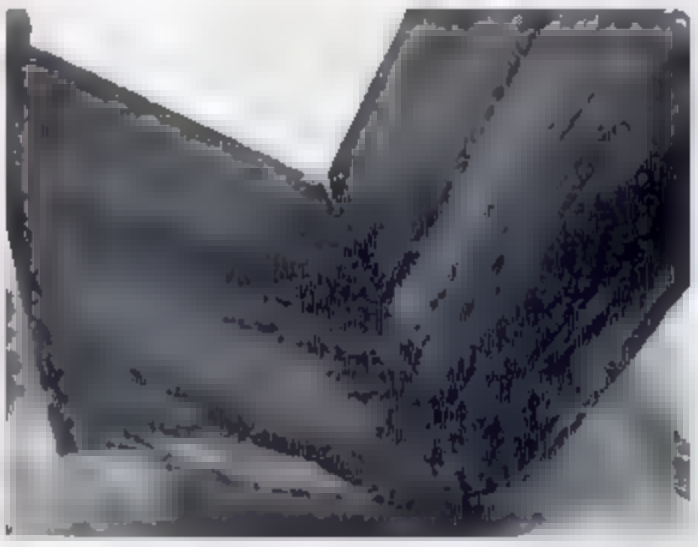
I do not use blueprints or designs. I simply look around for an existing birdhouse, on a tree, in a shop, in a magazine, or on the Internet. Then, with that idea in mind, I pick out a piece of petrified wood that I think will cut to that size and shape.

After picking out your wood, cut as many ¼-inch slabs as

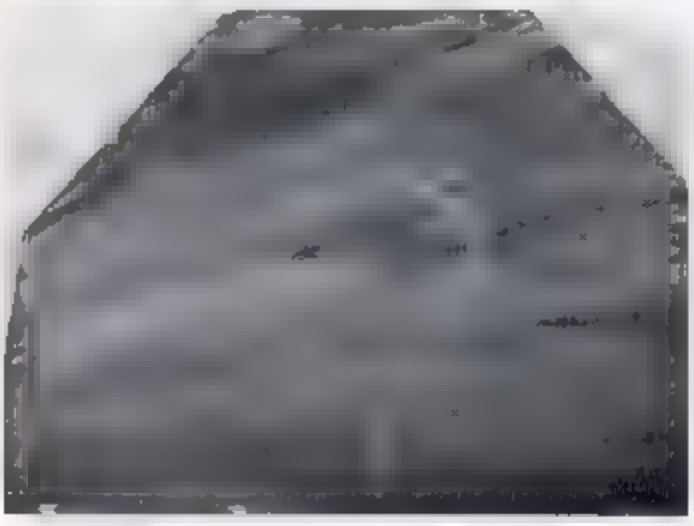
continued on page 55

PROJECT

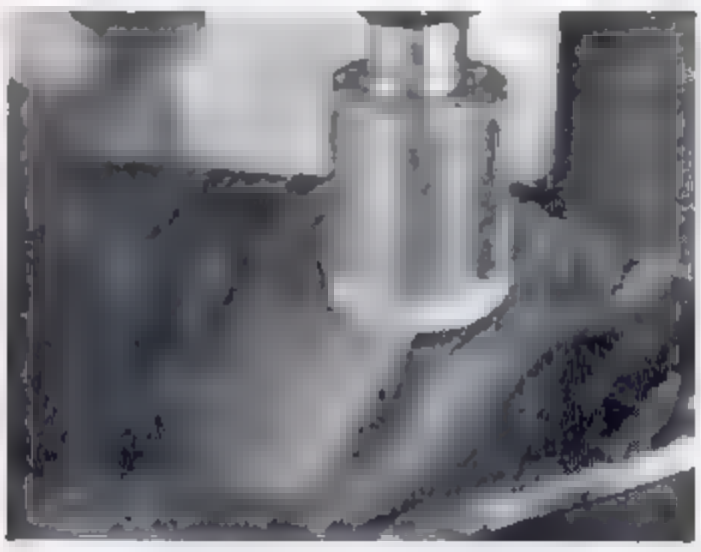
Build a Rock Birdhouse *from page 51*



Extra epoxy inside the roof seam will build up the inside crevice, giving it additional strength.



Lay out the position of the bird hole on the front panel.



Cut out the bird hole with a 1¼-inch round diamond saw.

Use a Dremel tool to name and date the bottom of your birdhouse.

you can. Save all the pieces, even the end slabs, they add texture around the outside as decoration. I used two rocks: one for the basic shape and a larger one for the roof and backing material. The backing material will hold the front together, it will be your upright foundation.

The size of your slabs will determine what size you can make the basic structure. Lay out two longer and wider slabs for the roof and figure out what sizes you can make the other pieces.

I begin with the roof and cut both halves the same size, as large possible. The roof will need to be wider than the sides so it can protrude over the sides and front. You will determine the pitch after you cut the front wall.

I then choose a piece for the front wall that has the most character of wood grain and pattern. The front wall should be tall to give the birdhouse height. I didn't have an extra-long piece for the front, so I epoxied two pieces together to make a 4-inch-wide by 8 inch-high panel. The size of the side and bottom walls will be based on the size you picked for the roof and front. You build the birdhouse from the top down.

I measured the center of the longest 4-inch-wide front panel and drew a line from the top to the bottom. Then I marked a line from the top center to a spot 4 inches down each side. Cutting along the lines produced a 45-degree-angle peak. I placed this front top half on the backing material and positioned the top pitch just below the upper end of the backstop to help me determine the height of the front bottom panel.

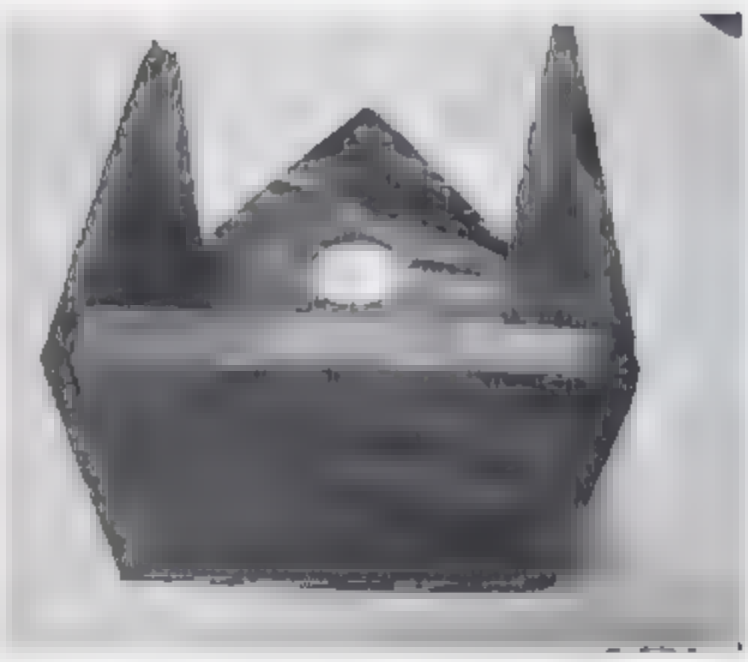
Mark all the pieces for cutting with an aluminum pencil. Be sure to label each one, if they are similar in size, it will be difficult to remember which one goes where. Cut the slabs to size.

The roof slabs for the birdhouse pictured measured 4½ inches square; the front panel was 4 inches by 8 inches; the sides were 4 inches by 3¼ inches, and the bottom was 3½ inches by 3¾ inches. All the slabs were ¾ inch thick.

Make an angled cut in the top edge of each roof panel. This requires a special setup, so I generally do this step last. To get the proper angle, I set the half of the front panel with the peak in the saw. I laid the best looking side of the roof slab – the surface that

continued on next page

Build a Rock Birdhouse *from page 55*



Start by epoxying one of the sides to the front panel then the bottom, then the other side.

Position the roof pieces so that the back ends are flush with the side panels.

Glue the assembly to the backstop and add decorative end slabs.

will be on the outside against the angled edge to align the edge of the roof panel with the saw. Clamp the piece in a vise to make the cut.

To lay out the bird hole, draw a perpendicular line with an aluminum pencil from the peak to the bottom on both sides of the front panel. Measure and mark the spot where you want your hole on the front and back.

I made the cut with a diamond hole saw about the same diameter as the decorative birds I purchased, 1½ inches round. Do a preliminary cut on the inside surface about ¼ inch deep. Flip the slab over and finish cutting the hole from the front. The inside cut will help keep the wood from fracturing and splintering when you break through with the hole saw. I use a spray bottle filled with water to cool and lubricate while cutting the hole.

Use a Dremel tool to sign and date the outside surface of the bottom slab, if you wish to.

Wash all your cut pieces with soap and warm water, and give them a good polish before you begin gluing them together. I like the two-part, 5-minute epoxy made by Loctite™. It dries quickly and seems to stick to everything. There are other two-part epoxies that work, but be sure to use the quick-drying type. If your epoxy takes 30 minutes to harden, your pieces may slip out of position while drying. Sometimes the epoxy is so strong that, if you try to break it at the seam, you actually break the petrified wood. I use a plastic tray and Popsicle stick to mix the two parts. It generally takes about two tubes of epoxy to complete the gluing of a standard-size birdhouse.

Start with the front and glue one of the sides to the back of the front panel. Use a square to be sure it is positioned properly. After the epoxy is hard, glue the bottom in place against the inside edge of the front and side. Glue on the remaining side. Hold the pieces in place with rubber bands.

Next, position the roof pieces on the assembly and align the back end with the ends of the sides. If you are satisfied with the fit and cuts, glue the pitch seam together. Once the epoxy is hard, glue the roof onto the lower assembly. Then glue it all against the "backstop."

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PROJECT

Rock Birdhouse *from page 56*

I decorated the birdhouse with some dried sage branches.

Add decorative end slabs to the front and sides to represent dirt or rocks piled up against the birdhouse.

If you weren't able to polish your cut pieces, now is a good time to cheat. Spray three to four coats of gloss lacquer onto the entire assembly, including the bottom. Be sure to allow time for a good drying between coats or you may get some fingerprints on the finish.

I decorated the birdhouse with some dried sage branches I collected from the same area in which I collected the petrified wood, and added some dried moss for bushes along the bottom. Glue on the decorative birds, and you're done.

DID YOU ATTEMPT THIS PROJECT? Send a photo of your effort and a brief description of your experience to **My Project, *Rock & Gem* magazine, 290 Maple Ct., Ste. 232, Ventura, CA 93003.** All entries become the property of *Rock & Gem*.

Reopening the Climax Mine

This Historic Specimen Producer Has a Rosy Future

Story and Photos by Steve Voynick

Climax Mine rhodochrosite shows good color and well-developed rhombohedrons, and is associated with slender prisms of clear quartz.

The Climax Mine, located 12 miles north of Leadville in central Colorado, is one of the more memorable mining sights in the western United States. From 11,318-foot high Fremont Pass on state Route 91, the mine appears as a sprawling industrial complex at the base of Bartlett Mountain. Even more impressive is the dramatically modified mountain topography that surrounds it.

An entire side of Bartlett Mountain has subsided into the "Glory Hole," a half-mile-wide, 1,000-foot-deep crater created by decades of underground mining and the removal of hundreds of million of tons of ore. To the south, the steep, uniform bench cuts of a large open-pit mine top out at the lofty elevation of 12,200 feet. And to the north, three huge tailing ponds as deep as 400 feet fill five miles of a mountain valley.

I once worked for a year at Climax, mining molybdenite ore and searching for specimens of rhodochrosite and pyrite. It was one of the very few places one could collect minerals at 11,000 feet above sea level while also being 900 feet underground. Finding great specimens was always a matter of being in the right place at the right time, and my luck was never quite good enough. I found many fine crystals, but my partners seemed to collect the great ones. That was no small achievement, given the fact that we weren't even supposed to be col-

eeting. When we did find specimens, we had to collect them quickly.

As drift-development miners, we were paid to drill, blast, muck and timber, not collect mineral specimens. Yet sometimes, while working in an isolated heading in a vast molybdenite ore body, we would burst into a small vug. Most were barren or lined only with small, clear quartz crystals. Occasionally, however, these vugs were filled with red rhodochrosite rhombohedrons, green and purple fluorite, and pyrite cubes. Just thinking about blasting into a rhodochrosite-filled vug helped to make the long, dark underground shifts a bit shorter.

Management frowned upon mineral collecting, or "high grading," as the miners called it, with good reason. It sometimes compromised safety and always decreased ore production. But high grading was part of the culture of underground mining, a tradition that many companies tried to stop, usually without success. Miners would always take the time to fill their lunch pails with valuable mineral specimens whenever and wherever they found them.

Miners justified high-grading on several counts. First, all mineral specimens that were not "saved" would be lost in the ore crushers. Second, if the miners on one shift didn't collect the specimens, they knew that their contemporaries on the next shift would. Third, good specimens were valuable, high-graders could either add them to their own collections or sell them for "bonus" income. Finally, many miners simply believed that high-grading was an earned "right," paid for by putting up with the darkness, dangers, and dreary conditions of the underground.

Right or wrong, miners took a lot of fine mineral specimens out of the Climax Mine in their lunch pails. In the 1970s, Climax was in full production and pro-

Talc slips are a near-perfect environment for the development of fine pyrite crystals.

viding a steady supply of specimens. Its rhodochrosite was unlike the translucent, pinkish specimens from other sources. The best Climax specimens were cherry-red, nearly transparent, and in well-formed rhombohedrons that could measure 2 or 3 inches. They were somewhat similar to the superb specimens from Colorado's famed Sweet Home Mine.

At Climax, pyrite occurred in a wide range of sizes, from delicate clusters of small, bright, sharp-edged half-inch cubes to fragments of 6-inch cubes. Both the rhodochrosite and the pyrite were often associated with green and purple fluorite.

Although high-graders focused on rhodochrosite and pyrite, it was molybdenite that brought Climax its true fame and fortune. Molybdenite, or molybdenum disulfide (MoS_2), crystallizes in the hexagonal system as short prisms, but is more often found as scattered scales and foliated masses. It is gray and opaque, and has a pronounced metallic luster and greasy feel. Molybdenite is very soft at Mohs 1–1.5 and has a high specific gravity of 4.7. Climax molybdenite is associated with microcrystalline quartz and forms small, gray-blue veinlets that lace a huge mass of altered, fine-grained silicified granite. Even the run-of-the-mill Climax ore, with its gray-blue molybdenite streaks and glittering bits of pyrite, makes interesting and attractive specimens.

But the Climax Mine has not produced much molybdenite or other mineral specimens since its operations stopped abruptly in 1982 following an epic collapse of the molybdenum market. Since then, apart from a few unsuccessful attempts at limited production, Climax has remained on standby status, with a skeleton crew tending only to water-quality maintenance and environmental reclamation.

Today, however, thanks to a restructured market and soaring molybdenum prices, Climax is preparing to resume production. Its reopening will be the latest chapter in a fascinating story of unusual geology, technological achievement, and the uncertainties of mineral economics.

The mineralization at Climax was emplaced some 30 million years ago following a massive granitic intrusion that erupted in four phases. Hydrothermal events followed each eruption, injecting superheated silica solutions rich in molybdenum and iron, with lesser

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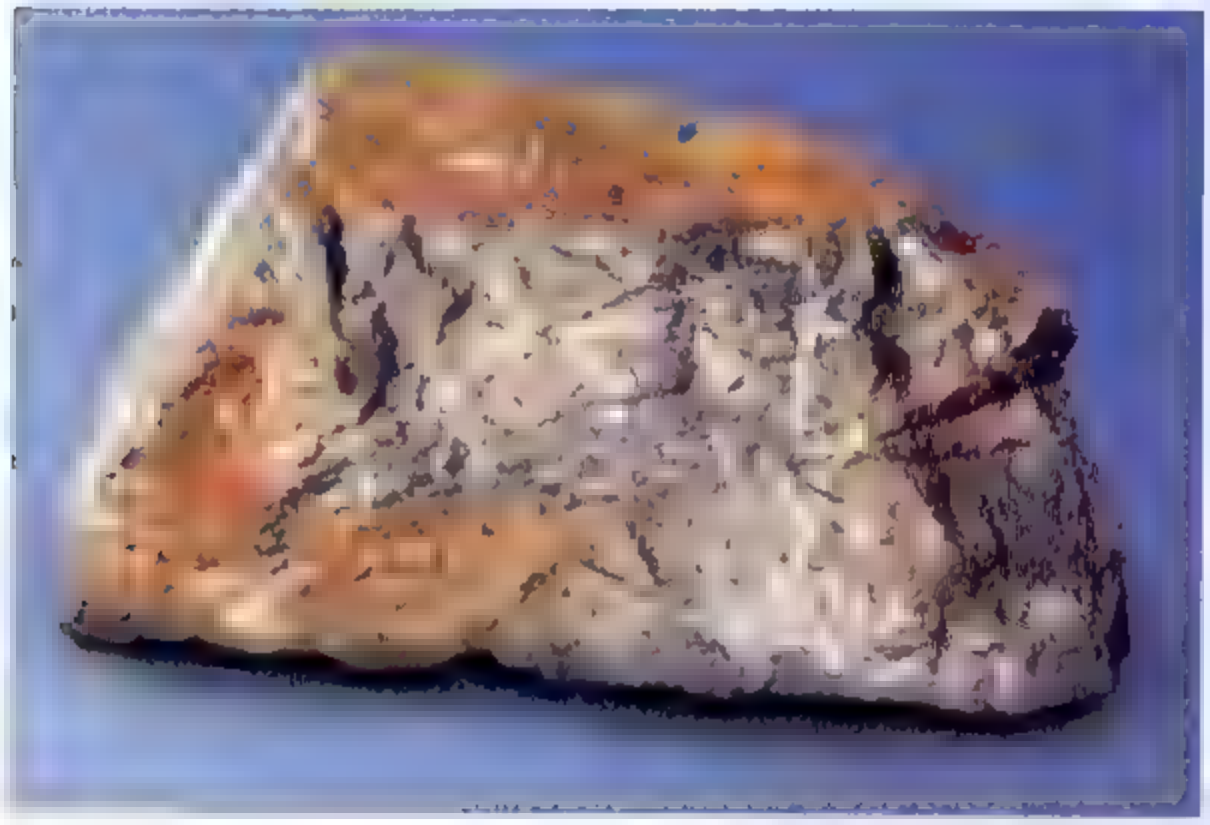


Specimens of Climax molybdenite ore show blue-gray quartz-molybdenite veinlets, as well as an exterior coating of yellowish molybdite (molybdenum oxide).

The unusual "cathedral" striation pattern on the face of this 3-inch Climax pyrite is due to parallel crystal growth.

amounts of tin and tungsten into adjacent fracture zones. These solutions first silicified the country rock. Then, as temperatures and pressure decreased, they deposited the molybdenum and iron as sulfides and the tin and tungsten as oxides. This emplacement formed the three cotamnar, superposed ore bodies that make up the world's largest known molybdenite deposit

The deposit was discovered in 1879, just as a silver boom was turning nearby Leadville into the West's biggest, wildest and richest mining camp. Among the thousands who flocked to Leadville was a mule skinner-turned-prospector named Charles Senter But Senter didn't stay long in chaotic Leadville, choosing instead to work small gold placers in the quiet subalpine forests north of Fremont Pass.

That summer, Senter investigated some strange, yellow outcrops high on Bartlett Mountain, where he found rock coated with a strange, dusty yellow mineral Breaking the rock revealed a light-gray crystalline interior laced with greasy, gray-blue veinlets. Whatever the yellow mineral coating and gray blue veinlets were, they made up most of the mountain

Hoping that this mineralization contained gold, Senter staked three claims, Gold Reef 1, 2 and 3 Assayers, however, reported no gold at all, suggesting instead that the gray veinlets might be unusual forms of graphite or lead.

A decade later, Senter was still trying to identify the minerals on his Gold Reef claims. This time, he sent samples to mineralogists at the Colorado School of Mines, who identified the gray veinlets as molybdenite, the only known ore of molybdenum, and the yellow surface coating as molybdite, or molybdenum oxide (MoO), the oxidation product of molybdenite. While this identification was finally accurate, it was also disappointing, for molybdenum was then a laboratory curiosity with no known uses.

At that time, molybdenum had only been known for a century In 1778, Swedish chemist Carl Scheele had identified molybdenum as a new element and molybdenite as molybdenum disulfide. Four years later, Scheele's contemporary, Peter Helm, isolated the metal as a dark, heavy powder with an extraordinarily high melting point Molybdenite, then thought to be rare, was obtainable only from small deposit in Norway Both molybdenum and molybdenite remained so obscure that even as late as 1890 assayers knew little about them.

French metallurgists began studying

molybdenum in 1892, finding a metal that was nearly as dense as lead, but with a melting point of 4,730 degrees F 2,000 degrees higher than that of most steels. Their most interesting discovery was that, when alloyed in small amounts, molybdenum dramatically enhanced the toughness, durability, and thermal performance of steel.

In 1900, German metallurgists also began researching the alloying potential of molybdenum, and with great success. When World War I erupted in Europe, the German army unveiled gun barrels and armor superior to any in the Allied arsenal. Upon learning that the superb German armaments consisted of molybdenum-steels, the Allies rushed to find their own sources of molybdenite.

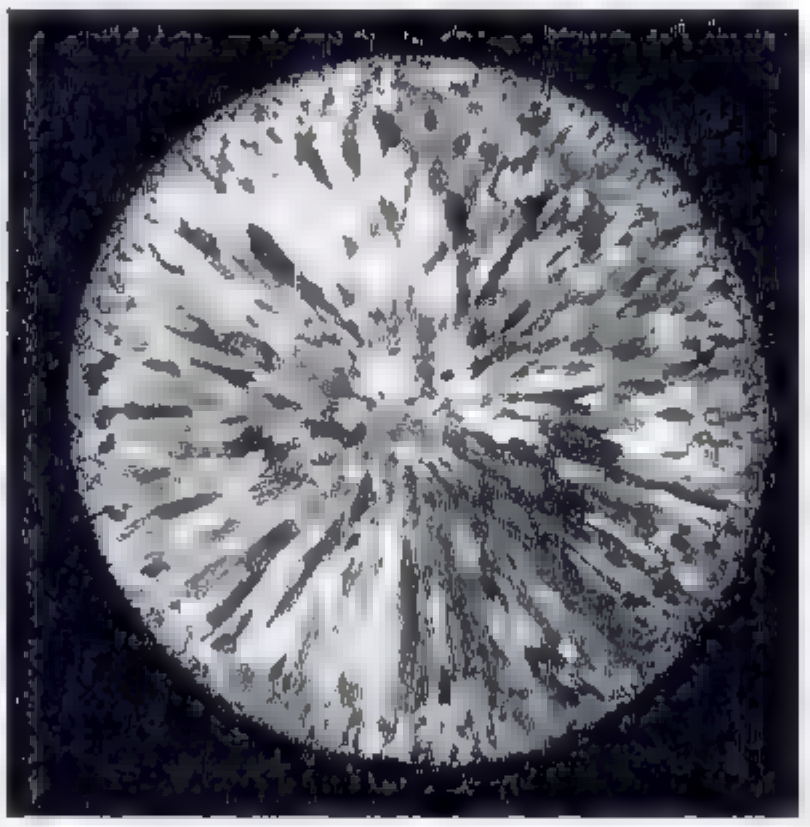
That focused attention on Colorado's Fremont Pass, which by then was a railroad water stop aptly named Climax, after the climax, or summit, of a steep rail grade. The arrival of droves of prospectors, miners and speculators in 1916 led to a year of exploratory "wildcat" mining, claim jumping, often-fraudulent stock promotion, and legal battles. But in late 1917, the newly formed Climax Molybdenum Co. emerged victorious, built a small mine and mill, and began shipping molybdenite concentrate.

In the end, patience paid off for Senter. Nearly 40 years after he investigated those yellow outcrops on the side of Bartlett Mountain, the Climax Molybdenum Co. bought his three Gold Reef claims for $40,000 — no trifling sum back in 1918.

Production at Climax lasted only until the molybdenum market collapsed with the Armistice of November 1918. Although the mine shut down, the Climax Molybdenum Co. didn't give up. It distributed its molybdenite stockpile free of charge to all steel companies that were willing to experiment with peacetime uses of molybdenum-steel alloys.

By 1924, molybdenum demand had increased just enough for the Climax Mine to reopen on a break-even basis, but the Climax Molybdenum Co. was deeply in debt and its directors realized that only mass-mining could make the low-grade ore profitable. In 1929, they committed everything to developing a massive block-cave mining system. Miners would first build a 30-mile-long network of rail drifts beneath the ore body. Then, if all went according to plan, the overhead ore, which comprised much of Bartlett Mountain, would settle and crush itself under its own weight. The broken ore would then move, mostly by gravity, into long lines of underground trams that would haul it to the crushers and grinding mills.

Climax survived the early years of the Great Depression largely by exporting molybdenite concentrates to Japan, Germany, and the Soviet Union at very little profit. But when the block-cave mining system became operational in 1933, its cost-efficiency surpassed even the wildest projections. Although other molybdenite mines now existed, none could match the low Climax price for molybdenite concentrate. By 1935, as the global steel industry recovered from the Depression and clamored for molybdenum, Climax supplied 90 percent of the market. Climax was then debt free and earning $5 million per year. Its stock had soared from $1 to $42 per share *after splitting three times*. It was the best performance of any Depression-era American company.



Molybdenum is a metal that is rarely seen in its elemental form.

Long, bitter winters and extreme elevation, however, made Climax a tough place to work and live. The rapid expansion had left the mine with a deplorable safety record that included eight fatalities and 47 serious injuries in 1938 alone, reason enough for miners to nickname it the "hellhole near the sky."

Nevertheless, Climax managed to improve working and living conditions and rose to its finest hour during World War II. Ordered by the War Production Board to produce far in excess of its designed capacity, the mine almost single-handedly supplied the huge amount of molybdenum that was critical to the Allied war effort.

After the war, Climax researchers developed new uses for molybdenum and its compounds in pigments, lubricants, and space-age alloys. To meet growing molybdenum demand, Climax continued to expand, and in 1958 it became the world's largest underground mine. By then, Climax was also recovering byproduct amounts of tin, tungsten and pyrite.

Climax had initially mined only molybdenite, or "sulfide ore," concentrating it by simple flotation separation. In the 1960s, however, the mine supplemented its output by mining molybdite, or "oxide ore," from the upper, weathered sections of the ore body. Climax peaked in the 1970s with 3,000 employees, 100 miles of underground workings on three levels, and a large open pit.

Climax had dominated the molybdenum market since 1918, and in the 1970s it still supplied half the world's molybdenum. Its competition now came from a number of smaller, open-pit, primary molybdenite mines and from several large, open-pit copper mines that had installed molybdenite-recovery mill circuits.

Copper and molybdenum have a mineralogical affinity, and many copper ores contain small amounts of molybdenum. Because Climax had traditionally held the molybdenum price to a low $3 per pound, however, only a few copper mines had installed byproduct molybdenum-recovery circuits in their mills.

Then the 1973 OPEC oil embargo upset the stability of the molybdenum market. Tight fuel supplies touched off a worldwide race to find new oil sources, sending demand for high-molybdenum drilling steel to record levels. The subsequent rising molybdenum prices encouraged several new, primary molybdenite mines to begin development and many more copper mines to recover byproduct molybdenum.

Although increasing, the molybdenum supply could not keep up with demand. By 1979, molybdenum prices had soared to $8 per pound. Metal-market analysts' warnings that the molybdenum industry was headed for overproduction were overshadowed by two factors. One was a strike at a Canadian molybdenite mine that temporarily curtailed supply, the other was the energy crisis of 1979 that again spurred demand for oil field steel.

In 1980, the price of molybdenum hit $15 per pound. But as Third-World copper mines were glutting the market with byproduct molybdenum, oil

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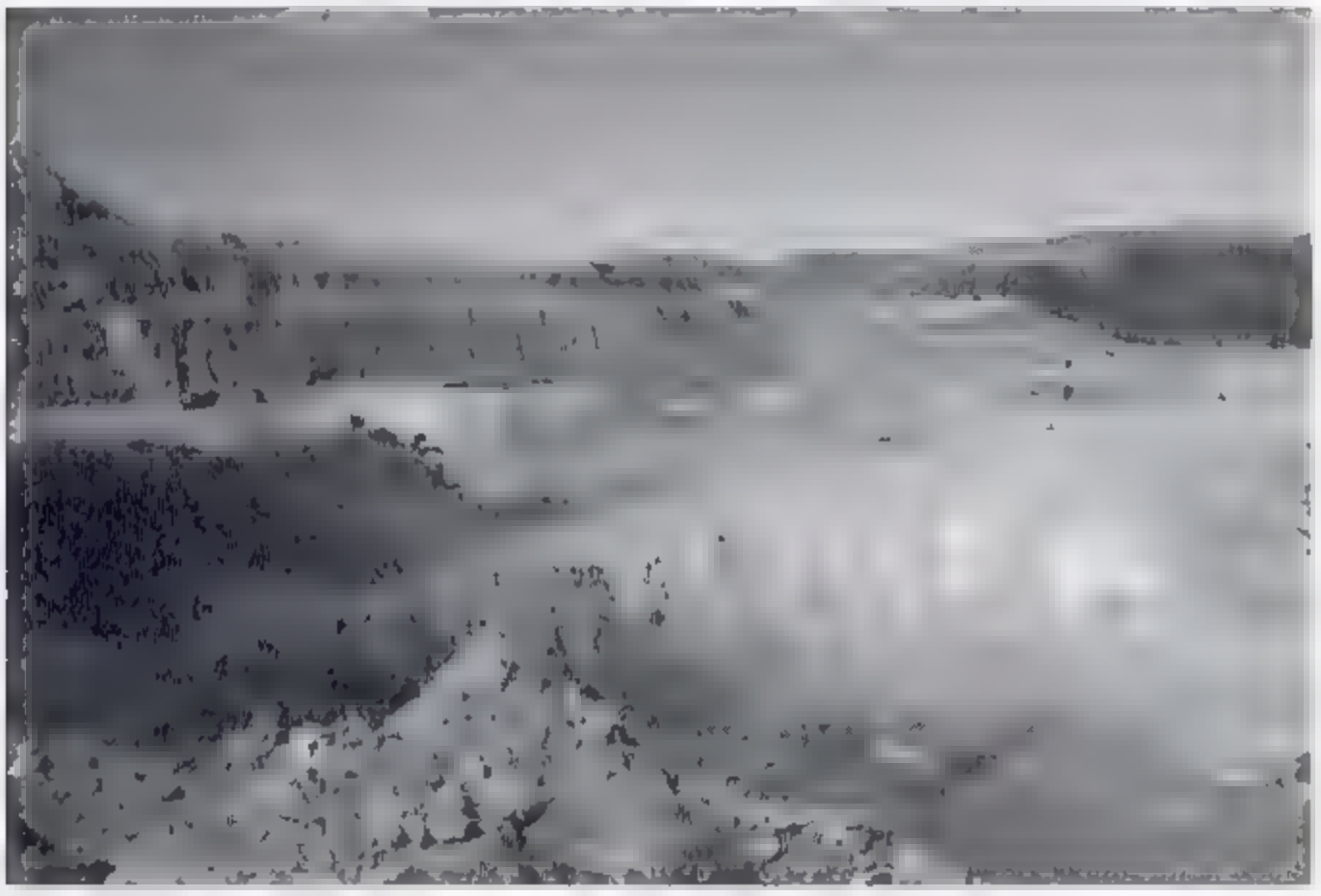

The open-pit portion of the Climax Mine is scheduled to reopen in 2009 and will produce about 15 000 tons of molybdenite ore per day

prices suddenly collapsed, killing demand for oil-field steel. Meanwhile, steel companies, facing a national economic recession, cut production and replaced molybdenum with cheaper, alternative alloying metals such as vanadium and manganese.

In 1981, the oversupplied molybdenum market collapsed. As molybdenum prices plummeted back to $3 per pound, the Climax Mine shut down. Leadville, home to most of the Climax miners, was devastated. Its population dropped by half, schools and businesses closed, and "For Sale" signs went up in droves. Within a year, Leadville went from one of Colorado's most prosperous rural communities to one of its poorest.

When the Climax closed, it still had 140 million tons of ore reserves. These reserves contained 400 million pounds of elemental molybdenum worth more than $1 billion, but the cost to mine a pound of the metal at Climax in 1981 was $5, while the market price was only $3.

Molybdenum prices remained depressed over the next two decades as copper mines supplied large amounts of byproduct molybdenum. But the molybdenum market was already changing radically with the emergence of a new player, the People's Republic of China, a nation in the midst of a phenomenal economic boom. Mineral collectors will recall the huge amounts of Chinese minerals that became available during the 1980s and 1990s, which directly reflected the rapid growth of Chinese mining.

During the 1990s, China opened 60 molybdenite mines. Although small by western standards, their collective production was substantial. China exported much of that molybdenum, a big factor in keeping molybdenum prices low. By 2002, however, China's booming steel industry had become so big that it needed the country's entire domestic production of molybdenum and more. As China suddenly became a net importer, molybdenum prices took off.

In 2005, the molybdenum price topped $20 per pound, enough for the Phoenix-based Phelps Dodge Corp., the new owner of Climax, to decide to reopen the mine. The cost of restarting the Climax Mine will be about $300 million, mostly for construction of a new mill. The huge investment should pay off, though, for the Climax ore reserves will be enough for 20 years of mining. This time around, Climax will be an open-pit operation only, at least for the first 10 years. That will mean big changes in collecting mineral specimens.

In the old days of underground operations, drift-development miners spent most of their shift working without direct supervision. Back then, the first thing miners did after blasting was to check for dangerous misfires, then hose down the "muck pile," the heap of newly broken ore, to keep down the dust. Hosing also revealed the colors in the muck pile, and miners watched closely for the brassy glint of pyrite and the red gleam of rhodochrosite. If miners did encounter a vug in the face, wall or back (roof), they collected specimens any way they could, breaking rock with hammers and picks, using ladders and crude scaffolds, sometimes even drilling a few "extra" holes and shooting them "lightly" — and doing it all quickly as possible.

Given its proximity to the Sweet Home Mine — only five airline miles to the southeast — it is not surprising that Climax is a good rhodochrosite source. The Climax rhodochrosite formed in late-stage emplacement veins at the edges of the ore bodies. It is mineralogically similar to that from the Sweet Home, being associated with pyrite cubes, slender crystals of clear quartz, small amounts of tetrahedrite, and green, purple and raspberry-colored fluorite. Although most of the rhodochrosite crystals found at the Climax are relatively small, I've seen miners collect 2- and 3-inch rhombohedrons.

Another former rhodochrosite-producing site of note is the old John Reed Mine, a small lead-zinc-silver mine a mile south of the Climax open pit and on mine property. The John Reed dumps were once a popular site for collecting cherry red rhombohedrons up to an inch in size, but collecting ended in the 1970s when Climax filled in the mine and reclaimed the dumps.

Another interesting underground feature at Climax is talc slips, seams in the ore body that are filled with white talc. Although talc slips often indicate unstable and dangerous ground, they are a fine environment for the development of beautifully formed, free-floating clusters of pyrite crystals.

In the old days of underground operations, miners got to "know" the rock. That won't be possible in a big open pit operation, where miners will operate electric shovels with 20-cubic-yard buckets, big down-hole drilling units, and 150-ton diesel-electric haulage trucks. Perhaps that's why Climax, for the first time ever, has contracted with a commercial collector, who will have the exclusive right to collect specimens.

Once blasting begins on the open-pit benches, I'm sure new vugs will be exposed, and some of them will be filled with rhodochrosite, quartz, fluorite, and pyrite crystals. Personally, I'll be glad to see Climax Mine specimens being collected again — even though it won't be in quite the same way as in the days of the underground high-graders.

DIVING FOR FOSSILS

Fossil Hunting's Final Frontier?

Story and Photos by Richard J. Jacquot

Fossil horse teeth can be found in many shapes, sizes, and colors in the river.

I will say that using self-contained underwater breathing apparatus (aka. scuba) for fossil hunting is definitely one of the more advanced and technical methods applied in recent years by collectors. When compared to the length of time man has hunted the land for the remains of our prehistoric past, the use of scuba diving could almost be considered a new technique.

My dive instructor, Jerry Fortenberry, had told me for years about the fascinating underwater world of fossil and artifact hunting. He did not lie. I was hooked from the very first dive. In fact, I was drift diving for fossils in the Santa Fe River 20 minutes after completing my checkout dives.

I think the most intriguing thing about fossil diving is the ever-changing environment. Sure, there are changes when collecting on land. Rainstorms wash up new material; work at fossil-bearing quarries sometimes uncovers something new; hurricanes and earthquakes can lead to new discoveries. Even with these events taking place, though, unearthing new hunting grounds on land can take a lot of time.

Rivers, on the other hand, change daily. Millions of gallons of water constantly flowing over limestone river bottoms expose new finds. Hurricanes can shift tens of feet of sand, exposing fossil-bearing gravel beds hidden for millions of years. What could take years to expose on land can take just a few weeks in the river.

The sense of adventure in exploring the unknown and the thrill you get when you find that first specimen are what make diving for fossils such a great experience. Also, consider that fossil and artifact divers are just a drop in the bucket compared to the number of rockhounds and fossil hunters

A successful drift dive in the Santa Fe River at Ginnie Springs, Florida, produces a bagful of fossil treasures.

A leg spur from a giant land tortoise is sometimes mistaken for an alligator tooth or claw.

scouring the land for specimens. This relatively small group has the ability to explore many miles of completely unexplored territory.

My first experience drift diving for fossils took place in June 2006, in the Santa Fe River at Ginnie Springs, Florida. I had completed my checkout dives in the springs and completed my written tests. I was now an official Open Water Diver. My instructor, Jerry, is a veteran fossil diver, and he knew I was ready to hunt. We snorkeled out of the spring and into the Santa Fe River. After drifting on the surface for several hundred feet, we put in our air regulators and descended to the river bottom to begin our "drift dive."

In a drift dive, when you reach the bottom of the river, you face into the current and slowly work your way back and forth across the river bottom, searching for gravel beds. While you conduct your search, you slowly drift downstream with the current. Once you locate a promising collecting area, you simply stop drifting and search the desired area. In some rivers, such as the Cooper River in South Carolina, the current can be strong. Some divers use a screwdriver or something similar to anchor themselves to the bottom in the current. In the Cooper River, Jerry dives the tide tables, which gives us about a three-hour window each day to dive with little or no current. This makes it much easier and safer to collect.

Ginnie Springs was developed in 1976 as a dive resort. The main attraction for most divers is the crystal-clear water and the extensive cave systems that run for miles underground. You must be a certified cave diver to enter the cave systems, which are very dangerous. Personally, I am a hunter of rocks, gems, fossils, and artifacts, none of which are in those caves, and I didn't lose anything in there, so I see no need to venture inside. Especially with the Santa Fe River just a few yards away and loaded with fossil treasures.

The current was mild in the Santa Fe that June day. We sat the bottom and began our search. Visibility was excellent at about 40 feet. I could easily see Jerry moving about the bottom looking for gravel deposits. The area of the Santa Fe River we were in is known to contain numerous Pleistocene (1 million to 1.5 million years ago) and Miocene (5.2 million to 11 million years ago) fossils. Some of the more common species are horse, deer, bison, alligator, turtle, glyptodont, armadillo, mastodon, mammoth and oredont. Shark teeth, usually small ones, can be found. I saw some mako and sand shark teeth, but they are not nearly as common as the other fossils.

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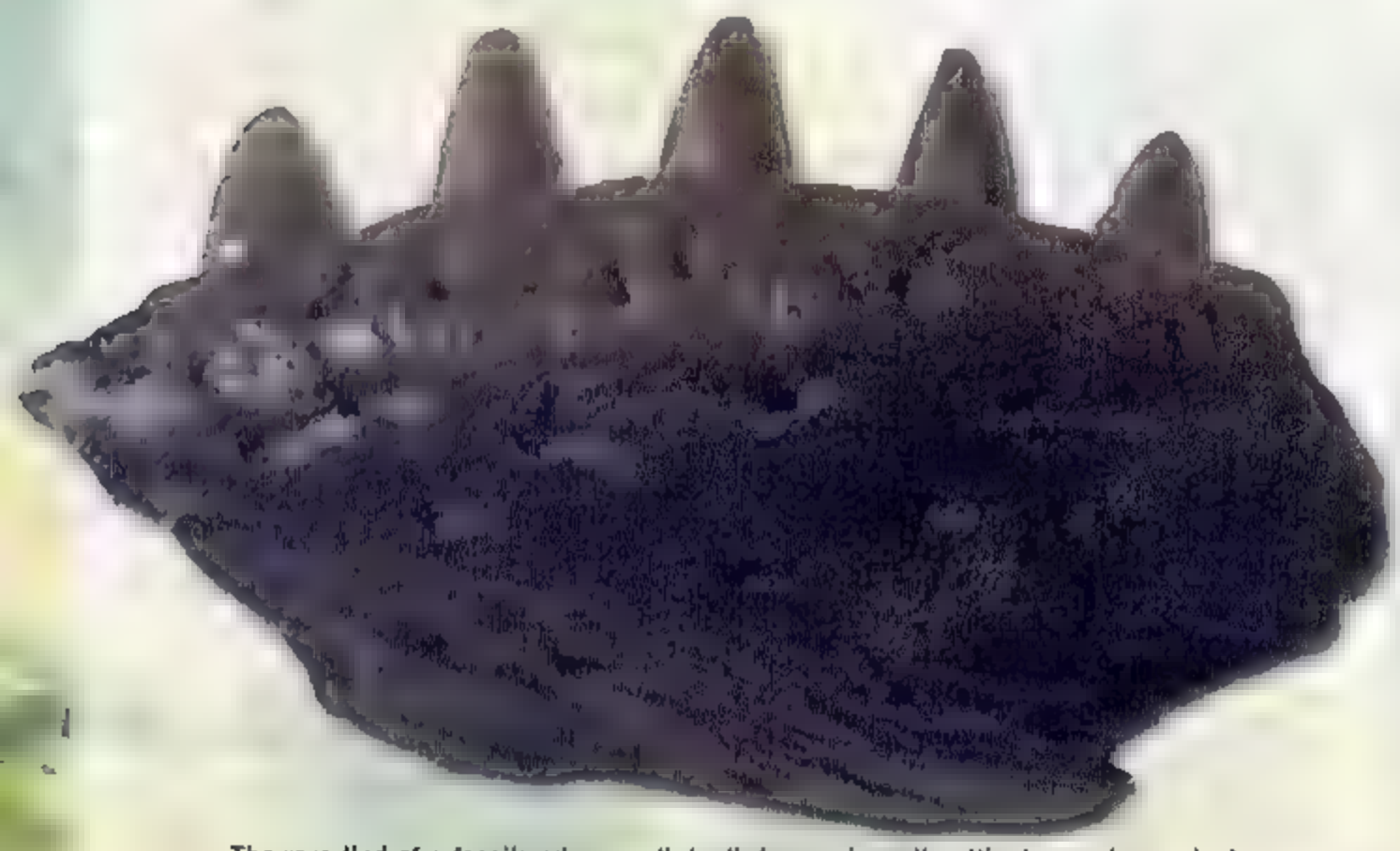
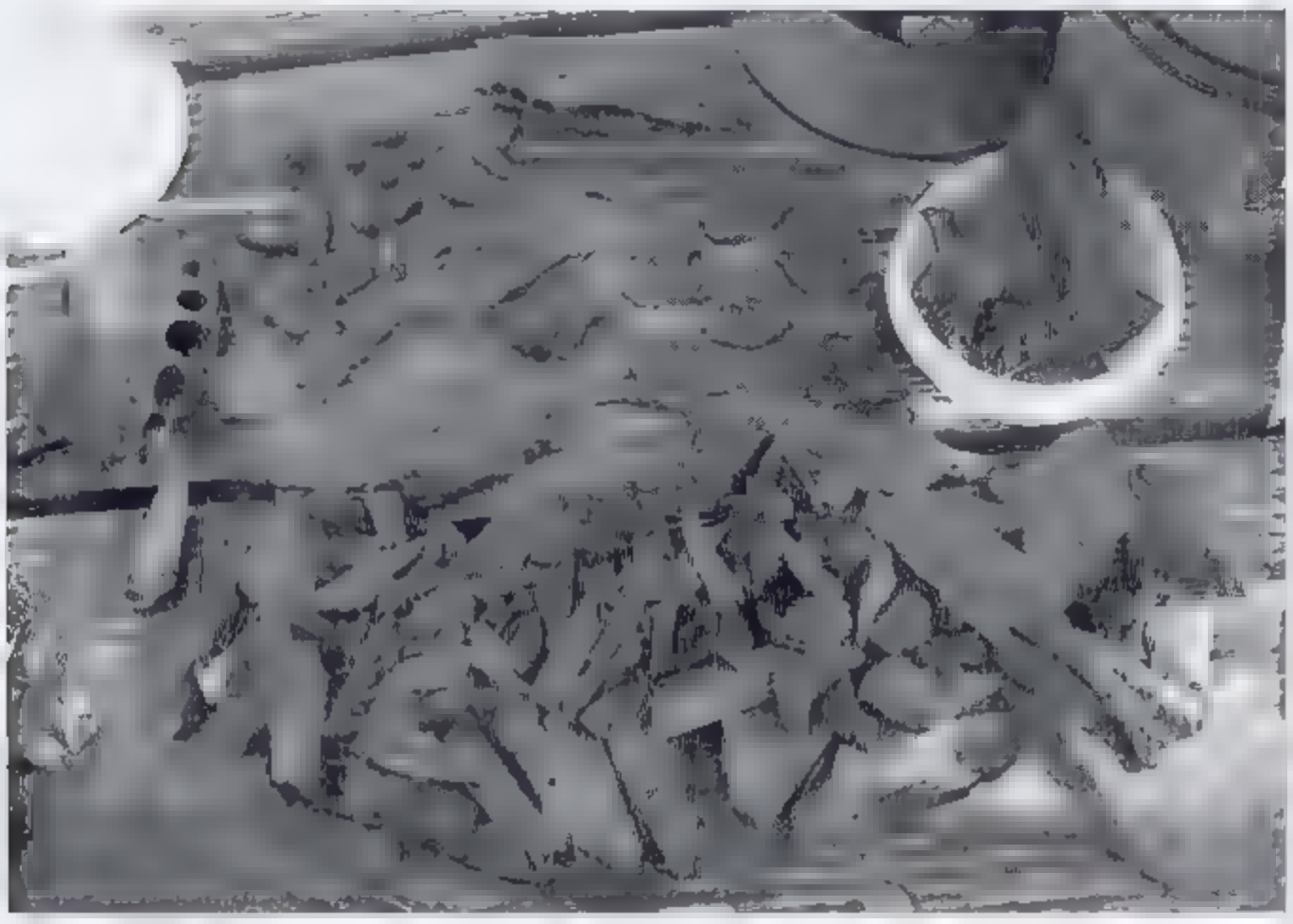


The rare find of a fossilized jaw with teeth from a juvenile alligator made my day!



Numerous skull fragments, teeth, and vertebrae from a Miocene alligator had collected in a clay pocket at the bottom of the Santa Fe River.

The technique for collecting is simple. Once you locate a promising gravel bed, use your hand to "fan" the sand and silt from the gravel. Then examine the area closely, pluck out the various fossils, and place them in your "goodie bag," a nylon bag attached to your dive gear used to store and protect your finds. The areas we were working are 18 to 25 feet deep. The shallow depth allowed us to conduct long dives, which was great.

You won't be alone collecting, even if your dive buddy moves off to another area. After just a few minutes underwater, I noticed I had an audience watching me and following my every move. About a half-dozen foot-long fish were hovering next to me as I flipped over rocks and fanned away the silt. At first, I just figured they were curious to see what I was doing until I flipped over a rock and a big crawdad jumped out from under it. I looked over just in time to see one of the fish swallow the crawdad whole! The fish were just using me to get a free meal.

At one area in the river, we came across a large amount of flint and chert. Here we found many Indian scrapers, pottery, and some points. Fossils and artifacts are not the only thing you can find. By the end of the day's dives, we had several pair of sunglasses, coins, jewelry, and an empty wallet. My best finds of the day consisted of two pond turtle nuchal scutes, a variety of Indian pottery, one scraper, one deer astragalus (ankle bone), several alligator teeth and claw cores, one nice horse molar, and one giant land tortoise leg spur, plus a pile of various fossil bones. I must say that I was extremely happy considering it was my first day of fossil diving. We conducted a total of eight dives in three days on that trip.

After that weekend, I spent several days throughout the summer diving the Cooper River in Charleston, South Carolina. Black water, zero visibility, and live alligators make that another story.

In September 2006, I was back at Ginnie Springs for another week of diving with several friends. Jerry, who was diving with me, Jerry's girlfriend, Tena, and John Deney and Pat Cummings. While Jerry and I were diving, the rest of the group waded in the shallow areas at the edge of the river and found some nice specimens.

The "astragulus," or ankle bone, from a Pleistocene deer is a fairly common find in the Sant Fe River

We conducted another seven dives that week. During the last two days, I hit upon an area that produced a huge cache of fossils, including a Miocene alligator skull that I retrieved from a clay pocket along with several vertebrae and other bones belonging to the same animal. After my first summer of diving and only 28 logged dives, I had found the best fossil specimens in my collection, so you can see why I am hooked!

Divers who hunt for and collect fossil specimens are considered "amateur paleontologists." I have always considered myself a "professional rockhound," since much of my income is derived from my rockhounding activities. Now I am proud to be part of the amateur paleontologist group. Fossil divers make up a large percentage of this group, especially in Florida.

Professional paleontologists are quite busy working at identifying specimens, teaching, publishing papers, and so on. This leaves them little time to get into the field to search for new locations. In fact, in his self-published pamphlet "Fossil Diving in Florida's Waters, or any other waters containing prehistoric treasures" (1998), Robert W. Sinnadd, Ph.D. writes, "it is estimated that 90 percent of all fossils in public collections were collected by amateurs." With the amateur collectors finding the specimens and the professionals identifying them, many significant new finds have been made. Over the years, this relationship has helped build quality collections for both groups.

The ethics for fossil diving are not much different than those for rockhounding. Respect private property and always obtain permission from landowners before entering their land, even if you are only on the land long enough to jump into the water. Some waterways may be restricted and off limits to fossil diving. To be a responsible collector, always check the regulations and rules for fossil collecting in the state you plan to visit. At my home near Asheville, North Carolina, I can collect gems and minerals on U.S. Forest Service land for my hobby and no permit is required. Fossil collecting is a bit different.

In Florida for example, a yearly permit is required, usually cheap at around $5.00 per year. The fossil diver should keep the permit with him at all times while diving. Collecting shark teeth, invertebrate fossils, and plant fossils does not require a permit. Each year, the permit holder sends in an annual report recording his finds. The state has a certain amount of time to request certain finds, if not requested, the fossils remain the property of the collector. To apply for a Florida fossil permit,

Indian artifacts like this large spear point may be found in the Santa Fe River.

write to Florida Program of Vertebrate Paleontology, Florida Museum of Natural History, University of Florida Gainesville, FL 32611-7800. All the rules, forms, and so on are explained when you receive your permit.

As with all things I undertake in life, I like to be well informed about what I am getting into. When I first started diving, I read numerous books on the subject. Three publications I would highly recommend are Simbaldi's "Fossil Diving in Florida's Waters," *Fossiling in Florida: A Guide for Diggers and Divers*, by Mark Renz (University Press of Florida, 2000), and *Florida's Fossils, Guide to Location, Identification, and Enjoyment*, by Robin C. Brown (Pineapple Press, 1988).

One of the most important things you should do before diving for fossils is make sure you obtain some quality dive training. Overall, diving is a safe sport, but no matter what the statistics claim, you are still venturing into an alien environment that requires the use of a life-support system. Proper training and the ability to comprehend and retain what you are taught is a must. Dive shops are located in many cities throughout the country. They can direct you to a qualified dive instructor, and many shops offer their own classes.

My theory for diving is "practice makes perfect." Even when I am not able to venture south out of the mountains for a fossil hunting expedition, I try to practice my dive skills at the local lakes. Cost can also be an issue. If you are on a limited budget, you may not be able to afford the $1,000 to $1,500 worth of equipment needed to get started. I would advise that you get your training first, then purchase one piece of equipment at a time. You will still be able to dive, most dive shops will rent you the needed equipment for a minimal fee until you can get your own gear. No matter how you do it, do it! It is an experience you may enjoy for a lifetime.

Fossil diving will open doors to a whole new world of collecting. To learn more about diving and to view reports of our fossil and artifact "dive safaris," visit my Web site, www.wnerocks.com, and click on the "Indy Jones Trading Company" link. To plan a dive vacation at Ginnie Springs in Florida, visit the Web site www.ginniespringsoutdoors.com. See you on the water!

This large nuccal scute from a Pleistocene giant pond turtle is a common find at the Santa Fe River site.

UNDERSTANDING Paragenesis

The Where, Why and How of Mineral Formation

Story and Photos by Bob Jones

A lovely scheelite on dolomite from the gold mine at Moro Velho, Brazil, must have formed at extremely high temperatures

EVAN JONES COLLECTION

Lovely orange dog-tooth calcite crystals formed at low temperatures and were colored by organic inclusions.

Have you ever wondered why there are no pegmatite deposits in the Midwest? If you want to dig for tourmaline or topaz or amazonite, you have to go into the mountains of the Eastern or Western United States. If you want to dig wonderful fluorite, superb calcite, and lovely, bladed celestite, however, you will be most successful in the quarries of the Midwest, for in the huge limestone deposits that cover the area, conditions are ideal for the formation of these lovely minerals. Suppose you want to dig the chloride minerals halite or sylvite. You're out of luck in the hills of the Appalachians. You'd better get out onto the dry salt pans, desert sinks, and dry lakes of the West to find these soluble minerals.

Certain rock types yield certain minerals. The rockhound can predict what minerals will be found in a given area by understanding its geology. Limestone formations, pegmatites, dry lakes, and hydrothermal ore veins each produce a specific range of species.

Zeolites, for example, are found in limited numbers in pegmatites, ore veins, and even evaporite deposits. To find the really good specimens, however, you had better

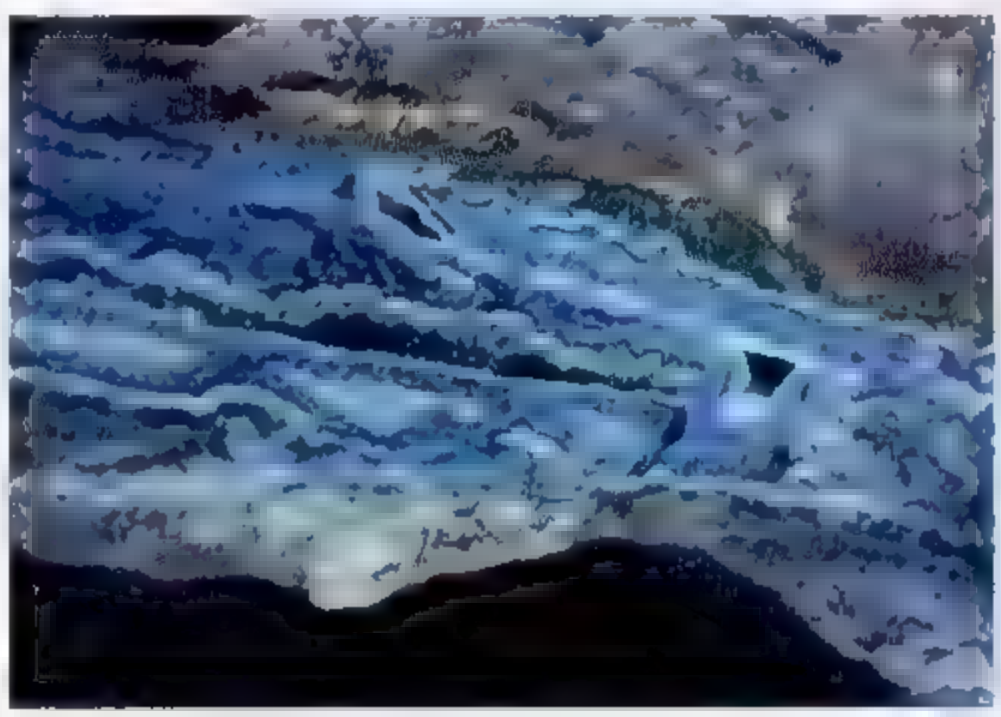
ve in or travel to the Northeast or Northwest, because these low-temperature species are best found in open vugs in basalt or diabase-type rocks: traprocks, as they are termed in the East. Today's marketplace is flooded with wonderful zeolites, and nearly every specimen you see comes from the Deccan Plateau of India. This vast volcanic formation is fraught with open vugs in which zeolites and their associated minerals, including stilbite, apophyllite, mesolite, cavansite, calcite, and even scheelite, can develop.

The primary factor that determines which minerals are found where is rock type. There are three major types: igneous, sedimentary and metamorphic. Within these rock groups, we find more specialized deposits caused by invading fluids. We can expect these deposits to hold specific mineral suites. For example, in very high-temperature igneous deposits, you ought to find cassiterite, schorl tourmaline, and tin, like the ancient deposits of Cornwall, England. The chances of finding a nice, gemmy beryl in Cornwall are remote because beryl does not normally develop under the same extreme temperatures. Topaz, however, does. So temperature plays a role in what forms where, and with temperature comes pressure, its constant companion.

It is important for rockhounds to understand the region in which they live or are searching because the rock types they encounter dictate in a large way what might be found. Don't look for fire agate in sedimentary deposits; fire agate is a product of basaltic rocks. Yet, if you collect barite or celestite, you will have the best chance of finding good crystals if you search limestone quarries and road cuts in the Midwest. Following this principle, prospectors devoted their efforts to searching igneous rocks, sometimes called crystalline rocks, the major source for gold.

Consider the critical role limestone plays in creating rich sulfide deposits. When metal-charged hydrothermal solutions surge up from deep in the crust, they encounter and penetrate limestone. If those fluids cannot escape, they drop their metal load, and the result is a broad suite of collector minerals ranging from fairly low-temperature gangue minerals like quartz, calcite and fluorite to higher-temperature gangue minerals like celestite and barite. Ore minerals—sulfides like pyrite, galena, sphalerite, chalcopyrite and many others might be found depending on what metals were in the hydrothermal solutions.

To complicate matters, Mother Nature influences variations within a particular species. Sphalerite, for example, can occur as black crystals in a tetrahedral form or as transparent, pale-yellow to brown or red crystals showing a rhombohedral form. The black form of this zinc sulfide is most often found in deposits formed at high temperatures, while the more colorful, often transparent rhomboids form at a lower temperature. So how do you explain the seemingly unusual occurrence of sphalerites from the Tri-State area of Oklahoma, Missouri and Kansas? Specimens of Tri-State limestone frequently hold dense black sphalerites *and* lovely little reddish, gemmy sphalerite crystals on the same or nearby specimens. The black sphalerites formed from solutions with a higher temperature, while later, lower-temperature solutions brought in the little red beauties as a secondary mineral.



It is not unusual for ore veins to show a sequence of formation, as evidenced by the layering of the copper species azurite and malachite.

One of my favorite minerals is apatite, particularly fluorapatite. It can be found in acicular crystals, tabular crystals, or lovely hexagonal prisms. The chemistry of all these crystal forms is virtually the same, so what explains the physical variations? The simple answer is temperature and pressure.

Where there is enough space for apatite crystals to form, the long, tapering, prismatic crystals—such as the lovely, needlelike, golden crystals from Tsumeb, Namibia—form at a fairly low temperature. In pegmatites, apatites form at a higher temperature, perhaps 800 degrees Celsius. These apatites are lovely, hexagonal prisms of modest length and gemmy form. In rock-forming terms, 800 degrees Celsius isn't a very high temperature, but water boils at 100 degrees Celsius. If you add pressure, water will boil at much lower temperatures.

When apatite crystals form flat, hexagonal discs, called "poker chips," the deposit has formed at an even higher temperature. At Lallagua, Bolivia, in the deep gold mine at Moro Velho, Brazil, or at the famous epidote locality at Untersulzbachtal, Austria, lovely poker-chip apatites can be found. The Bolivian apatites are white, the Brazilian crystals are pink, and the Austrian specimens can be violet, but they all show the same flat, hexagonal crystal form.

MINERAL ASSOCIATIONS

The key to mineral associations is related to each mineral's inherent desire to change from a liquid to solid form. Not all mineral species are the same, thank goodness. If they all solidified at the same time, we would get nothing but a fine-grained, solid mass with no visible, identifiable crystals. However, every mineral has a temperature and pressure point at which its molecules can no longer remain in solution, but gather together to form a solid crystal structure. Each species is part of an order of solubility. Any crystal that forms has to have a nucleus (a bit of dust, a sharp microscopic protrusion in a rock)—something to which the initial mineral molecules can cling and get a start. With a nucleus present, the temperature and pressure at which a certain mineral will leave a liquid state and start to solidify is called the point of saturation. The bit of dust or whatever is known as the site of nucleation.

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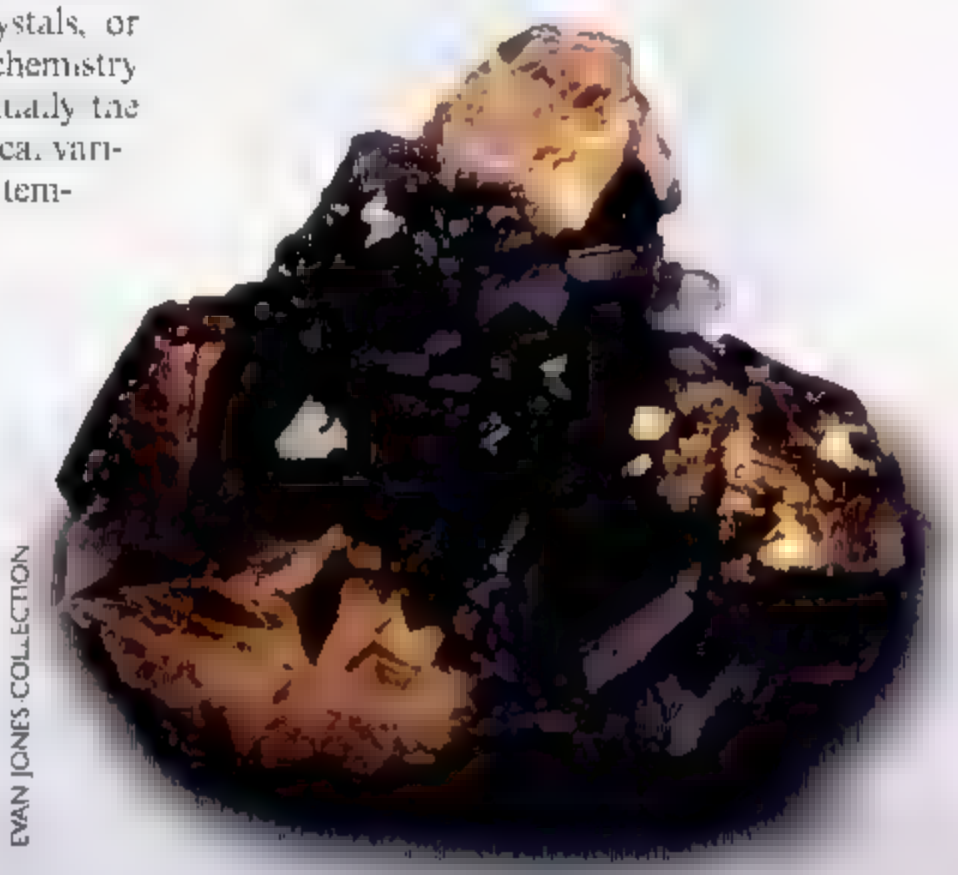
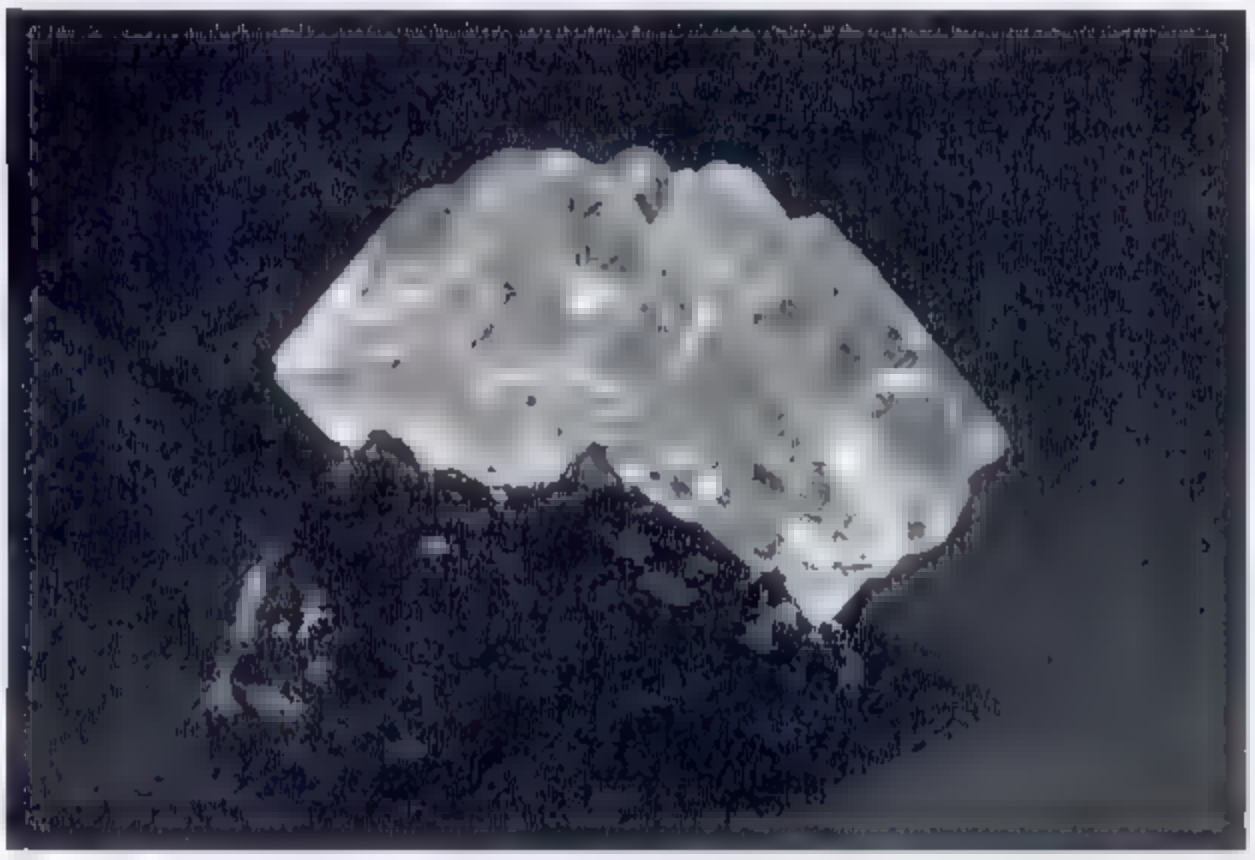


EVAN JONES COLLECTION

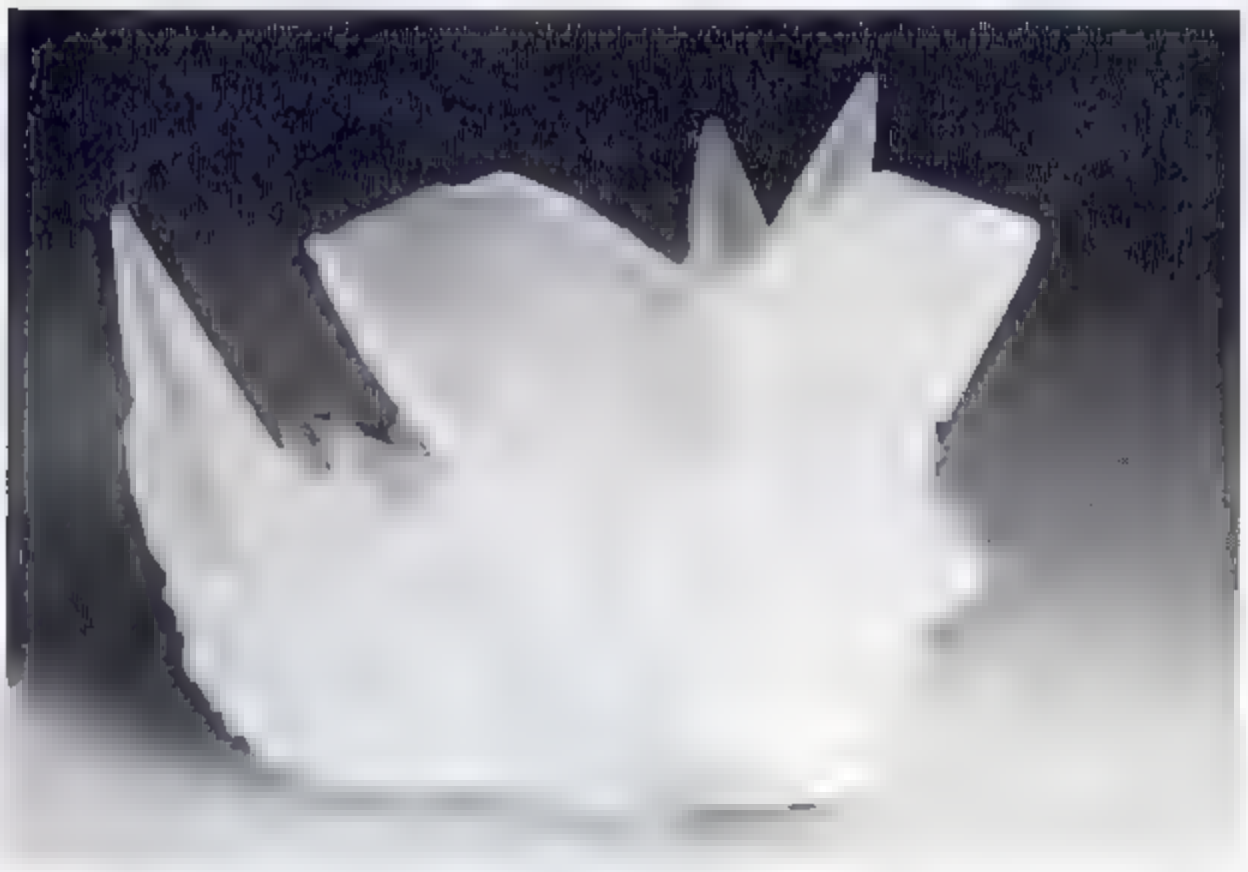
The interlocked crystals of sphalerite and chalcopyrite show that they developed at the same time.

Because of the differences in crystallization temperature, every vug you open and every seam you split will reveal a sequence of deposition. Those minerals with the highest point of saturation will form crystals or coat the walls of the opening first. As the solution continues to cool, each mineral crystallizes at its point of saturation.



EVAN JONES COLLECTION

In a classic sequence, the later-forming mineral fluorite sits atop the earlier-forming mineral galena from Naica, Mexico.



EVAN JONES COLLECTION

This specimen combines a calcite twin and a calcite scalenohedron, both of which form at fairly low temperatures.

Ideally, you would end up with a layer cake of minerals in distinct bands. In practice, the temperature, the richness of the solution, and the pressures involved cause variances in the deposition pattern.

The apatite crystals found in Austria are perched on epidote, a mineral that also forms at high temperatures. The epidote must have left the hydrothermal solution first. Another possibility is that the epidote formed from one solution and, after a period of quiescence, a second solution bearing the apatite ingredients infused the pocket and formed the apatite.

Gold is another mineral that forms at high temperatures. The apatites at the famous Moro Velho Mine in Brazil are well crystallized and a lovely pink, associated with siderite and glassy rock crystal quartz. These gangue minerals are found in deposits formed under high temperatures, but the main ore at Moro Velho is gold. It's this metal that makes it possible to continue mining at great depth. The greater the depth, the higher the original deposit-forming temperature, which explains the presence of the high-temperature gangue minerals siderite, apatite, and rock crystal.

Do not be fooled into thinking gold is just a high-temperature mineral. Gold can occur in high-temperature ore bodies like Moro Velho or as microcrystals in cold-water stream gravels. Scientists have shown that these microcrystals actually result from bacterial action in which some little cellular body coats itself with gold it extracts from the flowing water for protection. Eventually, the gold smothers and kills its host, while at the same time it provides a starting place for a gold crystal to evolve.

Aside from the gem-bearing pegmatites, which can be so specimen-prolific, the other major source of fine minerals is hydrothermal vein deposits, those fluid invaders that alter the host rock as they go and eventually start dropping a mineral-rich load along the walls of open spaces. Such deposits are further enhanced by weathering as descending waters dissolve minerals from above and bring them into contact with the original ores. That creates a suite of secondary minerals, many of which are highly prized by collectors and cherished by miners, since they tend to be enriched and easier to smelt to obtain the metals locked within.

Because of their great importance, hydrothermal deposits have been thoroughly studied. Not all hydrothermal deposits form at similar temperatures and pressures. Scientists have grouped hydrothermal deposits into low-, medium- and high-temperature ore deposits. Each has its own suite of mineral species. There are, of course, minerals that span the full range of temperatures within a given ore body, but mining engineers are skilled in sorting through this confusion to determine the original temperature of formation. This helps in understanding the techniques needed to mine and extract the metals.

Another reason for the natural variation in mineral suites is the manner in which the deposit formed. As ore solutions travel toward the earth's surface, they tend to cool, and pressures drop. Therefore, you find a gradual or subtle change in the mineral suites within a vein. This subtlety may only appear as variations in crystal modifications or even the types of species that occur. A good example of this gradual change can be seen in calcite.

Calcite is a gangue mineral that is found in all sorts of deposits ranging from cool sedimentary to hydrothermal deposits, regardless of the temperature

of formation. For example, the waters that formed limestone caves are about as cool as you can find, yet they produce small, usually dogtooth calcite crystals. The variety of calcite crystals in hydrothermal deposits can be impressive because this nearly ubiquitous calcium carbonate can take a host of crystal forms as the temperature and/or pressure changes. This was seen in the iron-lead deposits of England, where a variety of calcite crystal forms were found more or less in sequence during mining.

Calcite is the most stable form of calcium carbonate. The two other calcium carbonate species are vaterite and aragonite. Vaterite is fairly rare, while aragonite is quite common. Calcium carbonate can morph from vaterite to aragonite to calcite according to its stability. These are simply internal atomic rearrangements. Vaterite is the least stable form. As vaterite forms, it slowly changes to aragonite, which, in turn, can change to calcite. Interestingly, calcite can switch back to aragonite, as well. We often find what are called paramorphs: crystals that were and still appear to be aragonite, but have internally become calcite or, less often, the reverse of that.

The marvelous thing about calcite is that we have been able to identify no fewer than 300 different crystal forms for the one mineral. No other mineral is capable of such great variety. Of course, the variations are largely subtle — different sets of tiny faces here or an odd angle appearing there. Among these forms, we are most familiar with fewer than a dozen. These relate directly to temperature of formation.

I'm sure you recall the superb, snow-white, disclike calcites commonly called "poker-chip" calcite. These flat, platy crystals have a hexagonal form and are often opaque in the center and nearly water clear on the edges. They tend to stack, looking like a leaning pile of poker chips. The best known poker-chip calcites are from Charcas, San Luis Potosi, Mexico. One of the collecting trips I didn't make, and which I have regretted so many times, was to go dig at Charcas. During silver mining, a huge vug rich in poker chip calcite crystals was penetrated. These special poker-chip calcites were huge crystals like cart wheels, at least a foot on an edge. Imagine being able to dig crystals like that! Try as we might, we were never able to get permission to go into that working silver mine and gather those huge beauties, so all of them were lost during mining.

The poker-chip calcites form at relatively high temperatures. As the temperature slowly drops, the more common rhombohedral form shows up. These six-faced crystals look like a slightly flattened box and remind me of rhodochrosites without the bright red color. When I think of sources for this form of calcite, I immediately recall the superb, steplike stacks of these rhombs, often with curving edges, from Tsumeb, Namibia. Some are dusted with red hematite, while others are dusted with greenish dioptase. Many are water clear and very lustrous.

It's easy to see that the calcite formed after the stibnite on which it perches.

The next calcite crystal form to show up as the temperature drops is the hexagonal prism form, so common in the ore deposits of Missouri. The Viburnum Trend, in western Missouri, has produced superb, yellowish, doubly terminated hexagonal prisms. They tend to be a few inches long at best, with a cross section up to an inch or so. This same calcite form has been encountered in the Tri-State deposits. Keep in mind all these deposits can produce calcite crystals of differing forms. This is nothing more than a reflection of the changing environment as the crystals form.

Probably the best known — and certainly one of the most common and popular — crystal forms for calcite is the "dog-tooth" crystal. These pointed crystals are commonly found in plates from a few inches to many feet across, often covering the walls of mines. I used to dig in one old mine on an Arizona Indian reservation in which a wall about 100 feet wide and a dozen feet high was completely covered with 1- to 2-inch brown dog-tooth calcites. Time had been unkind to this wonderful array, people — I refuse to say collectors — did their best to smash and damage a lot of the wall area. But there were so many undamaged crystals that I collected to my heart's content.

The lovely, tapering dog-tooth crystals are especially common, as they form at ambient or near-surface temperatures, and they can occur in almost any environment. They are found in geodes, in vugs in sandstone, in limestone seams, on the walls of many deposits, and as the crowning touch on all sorts of earlier-formed associated minerals.

Certainly, the most remarkable recently worked limestone deposit is in the area of Elmwood, Tennessee. It is being mined for lead and zinc, but several very beautiful gangue minerals are found there, including spectacular orange calcite scalenohedrons (the technical name for dog-tooth crystals). They occur in amazing sizes and superb gem form. The crystals are clear enough to facet and large enough to provide faceted gems of several hundred carats. The color of these superb crystals is certainly not rare, since calcites found in limestone environments frequently have organic inclusions. Unfortunately, their color fades away if exposed to strong light long enough.

Another, more classic source for superb calcites is the iron and lead mines of England, which fueled the Industrial Revolution in that country. Particularly important to the science of mineralogy are the magnificent twinned calcites. Lovely, heart-shaped twins and choice twins that look like rabbit ears are much sought after today, even though mining in the Devon and Durham areas has long since ceased.

Aside from calcite, a host of gangue and ore minerals have come from hydrothermal deposits that developed under varying conditions. In the low-temperature deposits, temperatures just above and below the boiling point of water, calcite and quartz are present, along with fluorite, opal and zeolites. The ore minerals of low-temperature deposits are familiar to collectors, for they include wonderful prismatic stibnites and luscious red cinnabars. These two often occur together, with the cinnabars perched on contrasting black stibnites. Pyrite and marcasite can also occur at low temperatures.

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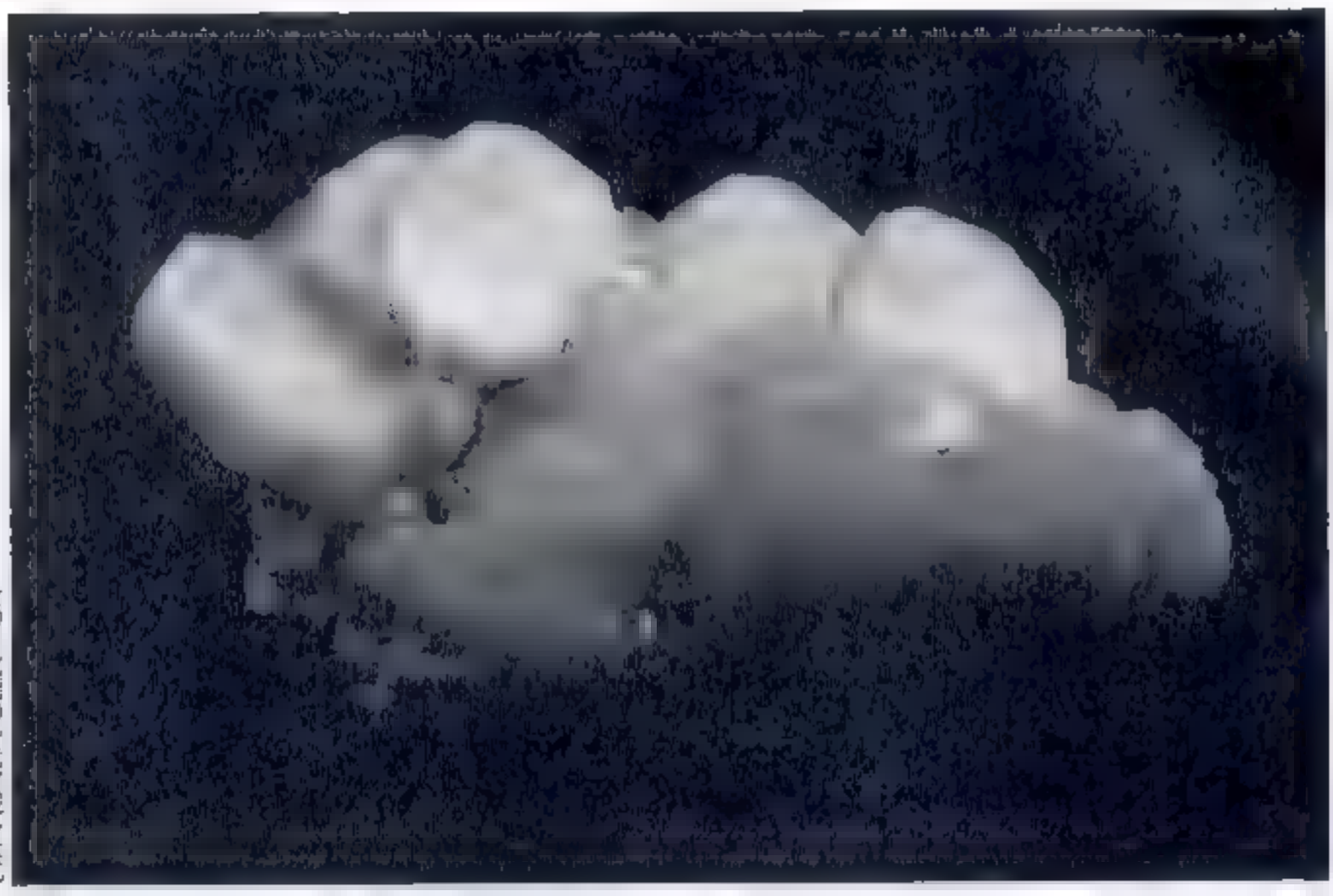

EVAN JONES COLLECTION

Poker-chip calcites are a well-known high-temperature crystal form.

The type of ore deposit that produces the greatest variety of collector minerals forms at about three times the boiling point of water. Mid-temperature deposits hold a host of sulfide minerals: galena, sphalerite, pyrite, arsenopyrite, and a nice variety of copper-bearing minerals (bornite, tetrahedrite, enargite and chalcopyrite). More important, these deposits produce gold in quantity. The collector minerals present include dolomite, siderite, and lovely barites, particularly the choice barites from the English deposits.

High-temperature deposits produce a different suite of minerals, but nothing like the collector species just described. You might find gold tellurides, cassiterite, magnetite, wolframite and garnet. They are of much greater interest to the scientist, though the serious collector prizes such species almost as highly as the showier, more colorful things.

As for the gem minerals, certainly the pegmatite deposits touch everyone's heart. Producing gem beryl, elbaite tourmaline, topaz, gem garnet, delicately hued violet kunzites, and a nice array of rare species, pegmatites are probably most collectors' favorite specimen source.

The range of species found in a pegmatite is considerable. In what we call common pegmatites, we find just quartz and feldspar, with a smattering of mica and maybe a bit of black tourmaline. The pegmatites rich in gem minerals are the ones we seek. They also yield really rare species like tantalite, cassiterite (rare in pegmatites), pollucite, and even zeolites. The Himalaya Mine at Mesa Grande, California, is one such specimen-rich deposit. Worked diligently these last decades, the Himalaya has become California's leading producer of fine elbaite tourmalines, among a variety of species.

In contrast, the Eastern pegmatites of Connecticut were loaded with common beryl and small amounts of rare minerals. One or two of the Maine pegmatites are noted for superb fluorapatite, with gem tourmaline the major gem mineral. The South Dakota pegmatites (especially the Tip Top Mine), North Carolina's Foote Quarry, and the very early classic locality at Branchville, Connecticut, are exceptional because they yielded a superb suite of phosphate minerals like fairfieldite and dickinsonite. Branchville, in Fairfield County, is the type locality for these rare minerals.

Observant collectors will take note of what they find during their digging efforts and extrapolate from that some of the conditions that were present during deposition. Such observations help in ferreting out the identification of some unknown minor species you might detect in the array of known crystals you dig. Time and constant observation are a great help to the successful, active collector. This explains why old-timers often astound the younger set by identifying what is in a rock and telling where it was collected. What appears to be mystical knowledge to the beginner is really only an insightful observation by the experienced.

Southwest Iowa Pyrite

Nonnative Rocks Yield Collectible Crystals

Story and Photos by Robert Beard

I have collected rocks and minerals throughout much of the United States, and I am generally able to find good collecting sites when traveling. Before I go to an area, I typically research it through my library of mineral collecting guides and the Internet. However, many times the information in collecting guides does not pinpoint areas well, and the Internet cannot provide the answers, either.

Small crystals of pyrite are in limestone rocks on both sides of the bridge.

In the spring of 2006, I was traveling in southwest Iowa and my schedule allowed me to look for collecting sites. I was in the area around Des Moines. I had a copy of Earth Treasures, Vol. 3, The Northwestern Quadrant by Allan W Eckert (iUniverse, 2000), which I used as my main collecting guide for this trip. This series has provided me with many good sites, but the directions are often out of date or not clear. In defense of Mr. Eckert, he does state in the beginning of his book that the directions are based on his best available information at time of publication, and that information on many localities was based on word of mouth.

I also purchased a copy of the *Iowa Gazetteer* (DeLorme, 2004), as many of the roads referenced in the collecting guide were back roads. Many of the directions referred to streams, rivers and lakes that would not be on larger-scale maps. The *Gazetteer* series is available for most states, and I usually find them for sale in the map sections of convenience stores in the states in which I am traveling.

Earth Treasures listed many sites in the areas in which I was driving, so I thought southwest Iowa would be a good place to find some rocks. Using the *Gazetteer* I was able to find most of the places mentioned in *Earth Treasures*, but I was not able to find a single site that had rocks for collecting. It began to remind me of the Monty Python "Cheese Shop" sketch, in which John Cleese tries to buy cheese at a cheese shop that has no cheese. He finally says, "It's not much of a cheese shop, is it?" I had to say that this part of Iowa, despite all the sites listed in my guide, was not much of a rock collecting place.

The biggest problem I encountered was the lack of outcrops. Many of the states that have thick sequences of sedimentary rocks, such as Ohio, often have huge road cuts in which millions of fossils are exposed, and finding rocks is usually not a problem. However, it seems that as you head into parts of the Midwest, it is often more difficult to find outcrops or road cuts. There are lots of excellent sites in quarries, but it can be very difficult to obtain quarry access on short notice, and I do not like to visit quarries as an individual. Quarry collecting is best done through mineral clubs and trips that are often arranged weeks or months in advance.

The terrain I was driving in was generally either flat or just slightly hilly, but flat is by far the best description for this area of Iowa. Unfortunately, I was stopped by the Iowa State Police for speeding in the middle of farm country. When asked what I was doing, I explained that I was trying to find some rock collecting sites before it got too dark to continue looking. Given the flat topography and absence of rocks, I think he thought this was the stupidest excuse he had ever heard. Luckily, I was not arrested and given a sobriety test. I showed him my copy of *Earth Treasures* as evidence that I was rock hunting and was able to talk him out of giving me a ticket.

I drove to many state and local park areas that had stream crossings hoping to see some rocks, but in nearly all cases the banks were muddy and did not have any rocks. The sites from *Earth Treasures* that I checked included a reported cone-in-cone calcite locality in Hamilton County near Stanhope. I arrived at the site, but I did not find any rocks worth collecting. This collecting guide also referenced many agate localities in creeks, but nearly all the creeks that I found were small, muddy drainages on private land that had no indications of rocks. If I thought there were really agates to be found, I probably would have gone wading, but the appearance of the creeks indicated that they were just muck. Any rocks would likely be pieces of solid limestone and not worth collecting. I had to find something really promising if I was going to get covered in a clay-manure sludge.

Near the end of my trip, I had all but given up and was returning to the airport at Omaha from Des Moines. I decided to take the side roads for one last chance of finding something. *Earth Treasures* described an area just east of Greenfield in Adair County that had some agate at the base of hills just south of the Thompson River. I took a slight detour and drove to the Thompson River, but again I struck out. I was not able to find the place, and the surrounding topography was mainly gentle hills, so I could not find any places with rocks. I figured that that was the end of any possibility of collecting.

As I drove north from Greenfield on state Route 25 toward Interstate 80, I continued watching the sides of the road for any indications of rocks. The topography became slightly hilly, and I dropped into a very broad valley. I saw a small bridge to my left, and thought that I saw rocks along the creek beneath the bridge. I turned left and drove over the bridge for a closer look. I was on 180th Street, and the creek was South Turkey Creek, according to the maps in the *Gazetteer*.

I was immediately intrigued by this site. Instead of mud, the creek and the banks were covered with large boulders and rocks. Many of them were quite large. They appeared to be rocks that had been placed for bank stabilization instead of outcrops. They were not evenly placed and were somewhat irregular. It appeared that many, many loads of rocks had been placed here, and they were on both sides of the bridge and creek.

Rocks for bank stabilization, often referred to as rip-rap, can yield some very interesting specimens. What makes these rocks unique is that they often are large and come directly from quarries. This makes them relatively unweathered, and rocks from quarries often have good minerals. Another good example of bank stabilizing rocks with collectible minerals was briefly mentioned in my article on sillimanite at Bellows Falls, Vermont (June 2005 *Rock & Gem*). The rocks on the New Hampshire side of the river had an abundance of radiating stibnite. In this particular case, they appeared to have been placed for stabilizing the bank of the highway as well as the bank of the river, so it pays to watch for large piles of rocks along roads, as well.

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The pyrite crystals are well exposed on weathered surfaces of the limestone rocks.

The site next to this small bridge was the only place in this part of Iowa where I had seen rocks after two afternoons of diligent searching for collecting sites. They were probably just limestone, but I hoped there might also be geodes or agates among them. I parked my car off the west side of the bridge and got out for a closer look.

Much to my relief, there were not any "No Trespassing" signs or other indications that the ground was posted. I have found that creek beds and areas immediately adjacent to roads and bridges are generally open to collecting unless they are clearly posted, as people are often accessing the areas for fishing and hiking. If they are posted, that means no access unless you can get permission, which can be very difficult, as it is unclear how to find the owner of a remote site.

I walked down to the creek with my hammer for a quick look. At first, the boulders simply appeared to be massive limestone. However, I found some crumbly areas and saw some gleaming, brassy yellow crystals reflecting the sunlight. These limestone rocks had sections that were full of crystals of pyrite. It was not massive pyrite, but aggregates of small crystals on broken and weathered surfaces. The pyrites were not bright gold, but slightly darker and iridescent, and may have also contained some chalcopyrite. Some of the crystals had terminated points that were revealed to be intersecting cubes on close inspection.

I began to look around and found that there were many other areas with pyrite among these rocks. I returned to my car for my backpack and camera. Since this was the first place I had found to collect rocks, my suitcases were empty and I had lots of available space.

The day was perfect for collecting: brightly sunny and no rain. I walked and climbed along the rocks looking for pyrites, and soon found that there were other features in the rocks. I found a crinoid calyx, but it was on a broad face that did not allow me to break it off, so I left it in place for future collectors. I also found some small vugs of calcite crystals that would have made a nice geode if they were in a separate rock. However, I found the best mineral to collect at this site was the pyrite. Many of the rocks I found had very distinct, well-formed crystals, and although they were small, they were definitely of collecting grade.

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This crinoid calyx may still be on a large block of limestone on the north side of the bridge on the west side of the creek.

Trimming from boulders can produce nice pieces with pyrite crystals.

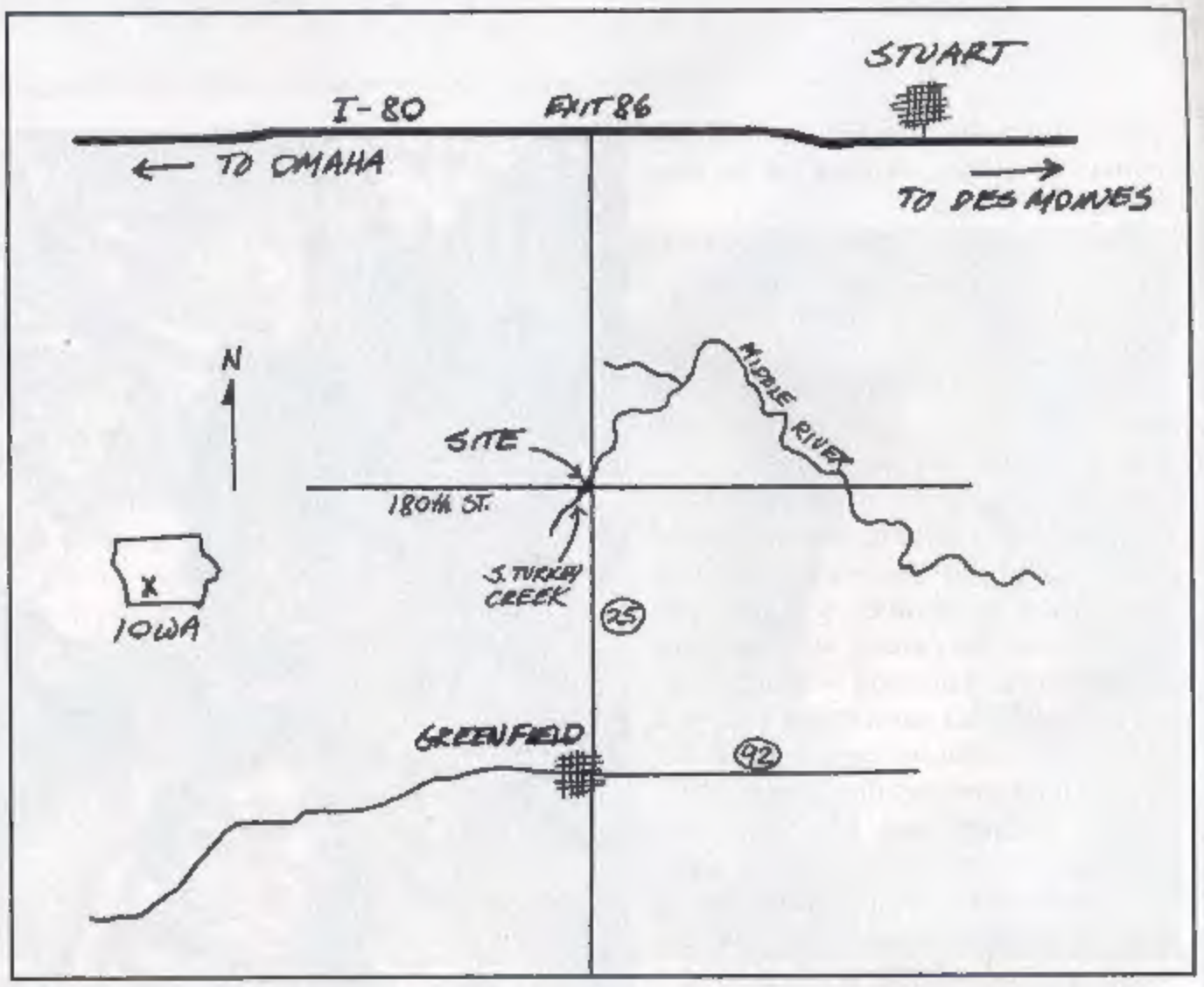
Some crystals have an iridescence that indicates chalcopyrite may be present with the pyrite.

The limestone ranged from light gray to dark gray in color. The pyrites could be found in both shades of limestone, but were most abundant in the dark-gray, shaley-silty limestone. A good guide for finding the pyrite was to watch for darker zones among the rocks. This darker, shaley-silty limestone was also easier to break apart with a hammer than the gray limestone. I suspect that the pyrite mineralization in the darker limestone was likely due to a reducing environment that formed when the shale was deposited with the limestone. A reducing environment is oxygen-deficient, and pyrite tends to form in such environments.

I also found that most of the pyrite was on the north side of the bridge. The rocks were abundant on the south side, but I did not find as many pyrites in this area. I also had my chisel, and I found this very useful for breaking out and trimming pieces with pyrites. I soon had reached my limit for collecting and left for the Omaha airport. It is important to note that while I was hunting for rocks, several cars passed and we gave each other friendly waves. I did not encounter any problems with landowners or anyone else over looking for rocks near the bridge.

This site is well worth a stop if you are traveling through Iowa and looking for a collecting site that offers good access and some immediate returns. You must climb a little on the rocks, and it could be easy to twist an ankle, but in general it is an easy site to which to bring kids or people who are not familiar with collecting. The best part is that hiking or 4-wheel-drive is not required. You can park and start finding pyrites within a few minutes, but I would recommend spending at least an hour at the site to find the best pyrites. Please bear in mind that at the time I visited the site, there were no indications that the land near the bridge was posted or otherwise off limits to collecting. Land status can change at any time, so watch for any newly posted signs or other indications that access may have changed.

To get to the site from I-80 Exit 86, take state Route 25 south approximately 7.4 miles. From Greenfield, take state Route 25 north approximately 5.9 miles. Turn west on 180th Street, and the site is on both sides of the road as it crosses South Turkey Creek. The GPS coordinates for parking, based on www.topozone.com, are 41° 23' 20"N, 94° 27' 12"W. Parking is best on the west side of the bridge and on the north side of 180th Street. The site is on the Rosserdale, Iowa, USGS 7.5 Minute topographic map, but this map is not needed to find the site.



I would never have found this site if I had not been diligently searching for areas with outcrops or rocks. This site is a good example of a man-made collecting site in an area that is otherwise barren of rocks. One should always be on the lookout for collectible minerals and fossils in areas with rock piles from construction, tunnels or rip-rap. This is especially true in areas of former mining districts and unusual bedrock geology, but all large rock piles, if accessible, should be checked to see what you can find.

The site looks like an ordinary stream crossing in Iowa farm country, but the rocks near the bridge are limestone with pyrite, fossils and calcite.

On the Rocks

Naica Revisited

At the 2007 Tucson Gem & Mineral Show, I heard a rumor that the lower levels of one of my favorite silver mines, at Naica, Chihuahua, Mexico, were flooded. According to the rumor, the miners, in their quest for ore, broke across a fault zone, and this released a deluge of trapped, exceedingly hot water. Probably meteoric in origin, the water supposedly filled the lower levels of the mine. This rumor was never confirmed.

When I heard this rumor, I was concerned because just a few years before, in 2001, I had been deep in that mine, marveling at a cavern holding the largest selenite crystals I know of in the world. The cave, now called Cueva de los Cristales, had been broken into during tunneling operations in 2000. The flood rumor was cause for concern because this amazing crystal treasure, 1,000 feet below the surface, may have been flooded. A hurried phone call to Naica by my friend Benny Fenn assured us that this most exceptional cave was still intact.

Another rumor I heard at the same show was that miners at Naica had broken into a second cave containing gigantic crystals. The implication was that flood water had poured forth from this new cavern, one that rivaled the earlier cave, and after the water had drained away, this second crystal cave was accessible. This rumor, too, was shown to be inaccurate.

The mine at Naica is worked for silver, lead, and other metals. It's one of the richer such mines in Mexico and is located in the Sierra de Naica Mountains. The amazing selenite cave was breached during mining.

Silver was discovered at Naica in 1794, but formal mining didn't get started until 1830. The giant crystal cave was discovered in 2000, when two miners drifting a ventilation tunnel broke into it.

What made the cavern so special was the huge crystals it contained. What made the cavern so scary was the reported temperature of 150 degrees F. We found out about the cavern when we saw photos taken of giant crystals estimated to be 50 feet long! After seeing those photos, I had no doubt of the crystals' size, for they dwarfed the miners standing next to them, and I was determined to visit the cave. You may recall my September 2001 *Rock & Gem* article about my trip. A group of people including my wife, Carol, and my son Evan were privileged to see this huge cavern crowded with monster-sized crystals of selenite.

Naica is in the state of Chihuahua, Mexico. From Phoenix, Arizona, it took about a day to get close enough to the mine to stay overnight. The next day, we arrived at the mine and were met by our guides. Before going underground, we were checked for safety equipment: steel-toed boots, hard hat, safety glasses, etc. I shouldered my camera equipment, which proved barely adequate, and we loaded into a truck. We took a couple of coolers with drinking water, and I had plenty of ice handy.

When we finally did get into the cavern, we had no chance to measure the crystals, but we were amazed! I went in and out of the cavern a half-dozen times on that first visit, but each time I climbed out I wondered whether what I had just seen was real or a rockhound's dream.

The cavern is really a nasty place to visit because the humidity is near 100 percent and the temperature runs close to 150 degrees F. Even forewarned, you are not ready for the blast furnace effect when you step inside. You know you've been in a scorching hot place when you step out of the cave and the 95-degree access tunnel feels like the air conditioner is running full blast!

What could be the cause of such heat and humidity? Obviously, as you go deeper into the earth, the temperature rises. When I was

Benny Lee Fenn strains to see the terminations of the huge crystals in the Cueva de los Cristales, Naica.

in the 4,800-foot level of the copper mine at Magma, Arizona, the temperature of the rock face was 148 degrees F. The miners who dug silver in the Comstock worked nearly naked and had barrels of snow lowered to them. They could only work for 15 minutes before taking a drink of cold water and getting an icy rubdown. The South African gold mines, the deepest mines in the world, are air conditioned so men can work in the steamy depths a mile or more down.

These mines, as well as Naica, are all metal-ore mines. Ore deposits like these are emplaced by hot solutions rising from a magmatic mass deep in the earth. As molten magma works its way toward the surface, hydrothermal solutions follow faults and cracks toward the surface of the earth. As hydrothermal solutions cool, the minerals they hold gradually crystallize. Those that crystallize at high temperatures form crystals first, and the solution becomes concentrated with minerals that develop crystals at lower temperatures.

At Naica, the original magma chamber is deep under the Sierra de Naica Mountains, and its heat and high humidity rise through the rock, accounting for the high temperatures and humidity encountered during mining. The faults in the Sierra de Naica region give the heat and humidity a pathway to reach the cavern. Hot, mineral-rich solutions undoubtedly rose and flooded the cavern, and when conditions were reached for crystal growth to begin, the cavern become host to crystals of whatever mineral the solution contained.

You may wonder why such well-known caverns like Mammoth Cave and Carlsbad Caverns are not humid and hot. Simply put, they are not associated with metal ore deposits, and they are close to the earth's surface and open to the atmosphere. Any heat they may have had has long since vented.

A three-quarter-ton flatbed truck hauled us down a spiraling tunnel to nearly 1,000 feet below the earth's surface. As we descended, the temperature gradually rose, and by the time we stopped near the cavern, it was well over 90 degrees. We were not taken right to the cave entrance, which we had heard was barred by a huge steel door. Instead, we had to walk a couple hundred

yards along the darkened tunnel the miners had been drifting when they broke into the cave.

Even with only head lamps to light the tunnel, we could see small, crystal-lined vugs and crystalline selenite everywhere. Under normal circumstances, we would have stopped and collected crystals, but reaching our goal was far more important.

Finally, we came to a small oval opening. For a minute, we thought we had reached our destination. We had not. When we climbed a ladder and crawled into this cavern, we found ourselves in a hot fairyland of giant selenite crystals! This cavern was simply a sideshow to what we were seeking, but it, too, held wonderfully large crystals, 20 or more feet long. The walls were covered with crystalline selenite. Evan even climbed the wall a short way. If you held a light against the wall, the entire layered selenite mass glowed a bluish white.

Proceeding along the main tunnel, we came down a short, well-lighted adit with whitewashed walls to a huge, white steel door. This was the entrance to a cavern containing the biggest selenite crystals in the world. The lock was shrouded by a horizontal half pipe of steel welded to the door. Our guide had to twist sideways, shove his arm and hand, with the key, into that half pipe, and figure out how to insert the key into the lock. He made it on his second try! Before opening the door, he reminded us not to walk too far into the cave. He also said one of our three guides, who included the two fellows who had actually breached the wall, had to be in the cave at all times when any of us were in there.

When the big steel door was opened, it felt as if someone had opened the door of an oven. In the confined space of that small tunnel, the initial blast took us aback. After the initial shock, we took turns getting a first look at the largest selenite crystals in the world. Even though we had seen photographs, none of us were really ready for what we saw: crystals as thick as tree trunks and as long as telephone poles. Some crystals lay horizontally and you could straddle them like a horse. Other huge single crystals were tilted at a jaunty angle, as if to flaunt their size. Several touched the ceiling, which had to be at least 30 feet above us. Covering the floor were selenite crystals of all sizes. You actually had to walk or climb on selenite, both massive crystalline and crystallized.

The reddish-brown ceiling sported some fabulous roselike clusters of selenite crystal aggregates that looked to be many feet across. These hung like crystal chandeliers in a room blessed with myriad giant crystals. The larger crystals showed some striations. They were of such diameter that their normal transparent property was slightly clouded. They lacked color. The light that entered was diffused by the thickness of the crystals. Two people could barely grasp hands when reaching around the larger crystals. Surprisingly, we saw no crystals with dirty or dark inclusions.

Benny Fenn works his way into the Cave of Swords, Naica. The crystals are about 6 inches long and are evidence of rapid crystal growth.

As for terminations, most crystals grew right to the ceiling. The free-standing crystals often had splintery terminations, which gave the terminations a somewhat serrated appearance in a series of what would normally be called "feathers," but you can hardly call 6- and 8-inch-thick crystal termination shafts "feathers."

There were no small crystals that I could see. There were only the monster prisms, which stood like wind-blown trees, and clusters of tightly intergrown monoclinic crystal ends, which jutted from the floor and wall like exaggerated shark's teeth. It was a fairyland of crystals, quite unbelievable when first seen!

Getting photos in such a hot and humid environment as the the Cueva de los Cristales is a challenge. First of all, you can't stay in the cavern for more than a few minutes without being smothered by the heat and heavy humidity. Second, the humidity instantly fogs a camera lens. So it was a matter of point, wipe the lens, and shoot. The results were marginal at best.

The humidity and intense heat made us really nervous. We felt as if we were suddenly unable to breathe. The fear of being smothered was as real as the crystals before us. It took a real effort to stay in the cavern for several minutes before succumbing to the need to breathe normally. I had armed myself with ice cubes in my photographer's jacket and shirt pockets, and I wore a golfer's frozen neckerchief around my neck. These precautions helped, but only a little. I'd stay in the cavern about five to seven minutes, then bail out to the "cool" 95-degree access tunnel.

After a half-dozen such forays, we were informed it was time to leave. On our way to the surface, we were given a chance to visit the Cave of Swords (Cueva de las Espadas). This remarkable cavern has been a showplace for the better part of a century! It was discovered in 1912 and later described by several scientists as the site of the world's largest crystals.

Not long after we were in the Cueva de los Cristales, the mining company (Compania Peñoles Unidad Naica) grew tired of the constant and persistent requests to visit the cavern. It sealed the cavern off so no one could enter, but only view it through a transparent shield. Only scientists were allowed into the cavern.

To the great credit of the mining company, the decision was made to not only preserve both the Cueva de las Espadas and the Cueva de los Cristales, but to allow scientists from Mexico and the University of Granada, Spain, to enter the cave wearing protective gear and search for clues as to what had created such remarkable mineral crystal phenomenon. The findings of the scientists, initially published in *Geology* magazine and made public in a BBC news release, give a logical explanation of how these calcium sulfate hydrate crystals formed. For a summary of the scientist's findings along with a most superb theory, check my article "Naica's Selenite Megacrystals," on page 12.